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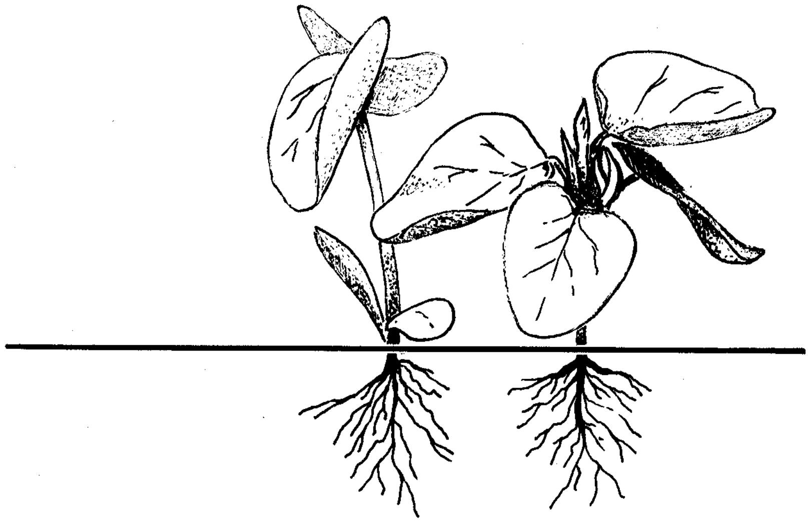

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H. D. Scott, J. A. Ferguson, R. E. Sojka and J. T. Batchelor[1]

INTRODUCTION

Yield and quality of agricultural crops such as soybean have increased dramatically in the last 30 years. This increase is partially attributable to improved tillage methods, greater fertilizer usage, improved crop cultivars and better methods of weed, insect and disease control. Regardless of the continuous improvement of crop management techniques, soil water stress remains the major limiting plant-growth factor even under the moderately humid conditions found in Arkansas.

Water management of soybean depends upon soil, climate and crop characteristics. Important soil characteristics include water pressure and hydraulic conductivity versus water-content relationships, cumulative soil moisture lost in first-stage evaporation, infiltration, internal and surface drainage rates, profile depth, bulk density and soil strength. Weather characteristics that affect soybean growth and development include atmospheric evaporative demand, rainfall, solar radiation and air temperature. In a given area these soil and weather parameters vary in amount, frequency and spatial and temporal distribution. Crop characteristics that are important to water management include cultivar, leaf area, canopy architecture and root distribution in the soil profile.

There have been a number of soybean water-management experiments conducted in Arkansas. One of the first published studies was by Bartholomew et al. (1) who reported the results of a nine-year study at the Rice Research and Extension Center near Stuttgart conducted between 1931 and 1939. The authors irrigated at certain dates, irrespective of soil moisture status; they found a highly significant, average soybean-yield increase of 182 kg/ha resulting from irrigation. Yield increases because of irrigation occurred in every year except 1931 and 1933 when the rainfall during July and August was substantial. Over the nine-year study period, yields of irrigated soybean ranged from 566 kg/ha to 1582 kg/ha and averaged 1044 kg/ha. This represented a 19.2 percent yield increase because of irrigation. They concluded that irrigation scheduling on preselected dates was not effective in maintaining high soybean yields since drought occurred between irrigations.

In 1941 Bartholomew et al. (1) redesigned the experiment, and irrigation was scheduled whenever the gravimetric soil-moisture content, determined once a week, was approximately 15 percent. This moisture content was approximately equal to the wilting coefficient of the Crowley soil. The responses of three soybean cultivars differing in maturity group to the new irrigation scheduling criteria were studied for

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three years. Over the three growing seasons the average yield of irrigated soybeans was 1458 kg/ha, which represented a 45.6 percent increase over the nonirrigated soybean. The number of irrigations during a growing season ranged from two to seven. They concluded that irrigation scheduling by determining the soil's water content was more effective than when water was applied on preselected calender dates.

Spooner (14) conducted irrigation scheduling studies on soybean at the Rice Research and Extension Center near Stuttgart on a Crowley silt loam between 1955 and 1959 and at the Cotton Branch Experiment Station at Marianna on a Richland silt loam in 1956 and 1957. There were four irrigation treatments, each beginning at a different stage of crop maturity, and two cultivars, one of which was Lee. The irrigation treatments were: (A) no irrigation; (B) no irrigation until bloom and then irrigation as needed throughout the remainder of the growing season; (C) no irrigation until the soybean began to set seed and then irrigation as needed throughout the remainder of the growing season; and (D) irrigation throughout the growing season as needed. Irrigation water was applied when 50 percent or less of the "available soil moisture" remained in the soil profile. Spooner (14) found that irrigation significantly increased yields in three years out of five at Stuttgart and one year out of two at Marianna. In addition, yields differed with cultivars in two out of the three years that yield increases were obtained from irrigation at Stuttgart, and they differed in one year at Marianna. It was concluded that irrigation water applied during vegetative growth had no beneficial effects on yields. More than adequate rainfall during June and July of these years precluded the need to irrigate during vegetative growth. Full-season irrigation (treatment D) increased yields by 26.4 percent over the nonirrigated control.

Thompson and Brown (17) conducted a deep tillage, massive fertilization and irrigation experiment on a Crowley silt loam at Stuttgart between 1960 and 1963. One of the objectives of their experiment was to study the effects of supplemental water on Lee soybean yields. The irrigations were applied whenever the station staff "judged" that irrigation water was necessary; the number of irrigations within a growing season ranged from two times in 1962 to four times in 1960. Thompson and Brown found that irrigation significantly increased yields in three years out of four with an average yield increase of 534 kg/ha. The average soybean yield of the nonirrigated plots during the four-year period was 2038 kg/ha. The results showed irrigation increased yields by 26.2 percent over the nonirrigated control.

Several additional reports have been written characterizing the response of soybean to irrigation in Arkansas (2, 4, 6, 7, 9, 11, 12, 16). The studies have generally concluded that yields of irrigated soybean are consistently higher than those of non-irrigated soybean, and that the magnitude of the response to irrigation depends upon the cultivar, soil and rainfall during the growing season. The reports also indicate the diversity of methods used to schedule soybean irrigation during the growing season.

The objectives of our study were to determine the relationships among soil water status, soybean growth and yield, and plant water stress; evaluate tensiometers as an irrigation-scheduling tool; and to measure root growth.

METHODS AND MATERIALS

Experiments addressing the objectives of this study were conducted for three growing seasons at two locations. Each location had a different soil composed of distinct physical and chemical characteristics. The study was conducted at the Rice Research and Extension Center (RREC) near Stuttgart and at the Delta Branch Experiment Station (DBES) at Clarkedale from 1974 through the 1976 growing season.

Soils of the Study Sites

The soils at RREC are Crowley silt loams, which are classified as a Typic Albaqualf in the very fine, montmorillonitic, thermic family. The soils at DBES are Kobel clays, which are classified as Vertic Haplaquepts in the fine, montmorillonitic, nonacid, thermic family. The Kobel soils are similar to the more widely known Sharkey soils. General profile descriptions of these two soils are given in Appendix Tables A and B. Selected physical and chemical characteristics of the soils at the study sites are given in Tables 1 and 2.

Soybean Cultivar

The soybean cultivar selected for this study was Lee 74, a midseason, moderately yielding cultivar of maturity group VI. Lee 74 resembles Lee and Lee 68 in most plant and seed characteristics except that it is resistant to rootknot nematodes and lodges slightly less than Lee 68 (3). Planting dates, estimated plant population and irrigation methods for the two locations are presented in Table 3. The soybeans were planted in rows 81 cm wide and 48.8 m long at RREC and 102 cm wide and 45.7 m long at DBES. The experimental design was a randomized block having at least four replications. Seedbed preparation, weed control and cultivation practices were those normally used at each experiment station. Plots were hoed manually as needed to control weeds. Determinations of plant growth stages were made according to the methods outlined by Fehr et al. (5). They are summarized in Appendix Table C.

Irrigation Criteria

Irrigation treatments were the same for both study sites and were designed to reflect a range of possible field irrigation-management practices. The three selected treatments were full-season irrigation (I), irrigation beginning at bloom (stage R2) (B), and no irrigation (N). For the irrigated treatments, water was applied whenever the soil water pressure approached -500 cm of water at the 30-cm soil depth. Each irrigated plot consisted of 12 rows with eight border rows. Generally, it was estimated that each irrigation added approximately 3.2 cm of water to the soil profile. The method of irrigation was either by furrow or flood (Table 3).

During the growing season, soil water pressures were determined in the row with tensiometers. In each treatment, a tensiometer with a mercury manometer was installed in two or more replications at the following depths: 15, 30, 45, 61, 76, 91, 107,

Table 1. Selected physical and chemical properties of the Kobel clay and Crowley silt loam soils at the study sites.

Soil	Horizon	Soil Depth	pH[1]	Organic Matter	CEC	Base Saturation	Sand	Texture Silt	Clay	Textural Class[2]
		(cm)		(%)	(meq/100g)	(%)		(%)		
Kobel	Ap1	0–10	5.7	3.18	50.2	75	2.2	39.4	58.4	c
(DBES)	Ap2	10–21	6.0	2.49	57.2	70	1.9	36.6	61.5	c
	Bg1	21–64	5.5	1.00	45.8	67	1.0	54.0	45.0	sic
	Bg2	64–108	5.8	0.69	42.9	79	1.3	55.7	43.0	sic
	Bg3	108–152	6.2	0.84	44.9	81	0.7	53.2	46.1	sic
Crowley	Ap1	0–10	5.2	1.58	18.2	46	3.2	78.1	18.8	sil
(RREC)	Ap2	10–18	5.6	1.39	18.8	48	3.4	76.1	20.5	sil
	Eg	18–37	4.4	0.69	13.7	28	7.0	72.2	20.8	sil
	Btg	37–75	4.7	1.17	43.3	24	1.3	36.5	62.2	c
	Bt1	75–98	4.8	1.07	38.7	39	1.6	43.6	54.8	sic
	Bt2	98–125	5.1	0.69	34.6	59	2.5	51.1	46.4	sic
	Bt2	125–158	5.5	0.52	33.0	75	3.0	53.4	43.6	sic

[1]1:1 soil to water ratio.

[2]c; sic; sil = clay, silty clay, siltloam, respectively.

Table 2. Additional physical properties of the Kobel and Crowley soils at the study sites.

Soil	Horizon	Soil Depth	K_{sat}	Bulk Density	Water Retained at Indicated Pressure (bars)						
					0	−0.1	−0.3	−0.5	−0.8	−1.0	−15.0
		(cm)	(cm/day)	(g/cm³)	(cm³/cm³)						
Kobel	Ap1	0–5	9.2	1.17	0.558	0.409	---	0.371	0.368	0.351	0.259
(DBES)	Bg1	21–42	0.4	1.45	0.453	0.336	0.325	0.317	0.314	0.309	0.276
	Bg1	42–64	1.4	1.48	0.442	0.316	0.301	0.292	0.284	0.282	0.279
	Bg2	64–86	1.1	1.48	0.449	0.335	0.317	0.301	0.297	0.291	0.269
	Bg2	86–108	4.3	1.57	0.408	0.305	0.289	0.277	---	0.270	0.222
	Bg3	108–152	0.1	1.56	0.411	0.335	0.320	0.307	---	0.296	---
Crowley	Ap1	0–5	77.2	1.17	0.560	0.360	0.265	0.258	0.234	0.223	---
(RREC)	Ap2	10–15	28.7	1.41	0.469	0.282	0.240	0.233	0.220	0.212	---
	Eg	25–30	5.5	1.52	0.426	0.248	0.220	0.214	0.203	0.199	---
	Btg	41–46	6.5	1.53	0.421	0.268	0.250	0.239	0.229	0.225	0.195
	Btg	61–66	0.1	1.40	0.473	0.363	0.348	0.342	0.334	0.330	---
	Btg	71–76	3.8	1.36	0.488	0.392	0.384	0.368	0.358	0.355	0.294

Table 3. Soybean planting dates, plants per hectare, and irrigation method used during the three growing seasons.

Location	Year	Planting Date	Plants per Hectare	Irrigation Method
DBES	1974	May 29	194,000	Furrow
	1975	May 20	129,000	Furrow
	1976	May 25	194,000	Furrow
RREC	1974	June 20	242,000	Flood
	1975	May 27	201,000	Flood
	1976	May 21	242,000	Furrow

122, and 137 cm. The soil water pressures were measured at least three times each week beginning early July and continuing until early September. Soil water pressures were calculated for each bank of tensiometers and averaged by depth and treatment. The daily average soil water pressures at the 30-cm depth in the plots with I and B treatments were used to determine the irrigation schedules.

Short-term soil water studies were conducted to further characterize the soil water status in soybean fields. The three studies were soil water pressure relative to distance from the row, diurnal variation of gravimetric soil water content, and water table fluctuations.

Climatic Data

Daily measurements of rainfall and maximum and minimum air temperature were recorded from the official weather records at each experiment station. In addition, open pan evaporation was recorded on a daily basis at RREC. The cumulative rainfall, pan evaporation and average air temperatures for the two locations and three growing seasons are presented in Table 4. The monthly summaries for these climatic parameters during the three growing seasons are presented in Appendix Table D.

Table 4. Summaries of rainfall, pan evaporation and air temperature at the two locations over the three growing seasons.[1]

Growing Season	Location	Cumulative Rainfall	Cumulative Pan Evaporation[2]	Average Air Temperature
		cm	cm	C
1974	DBES	69.6	---	23.9
	RREC	56.8	68.1	24.0
1975	DBES	20.0	---	25.0
	RREC	29.8	67.5	25.0
1976	DBES	29.5	---	24.7
	RREC	29.2	72.0	24.6
Long-Term Mean Rainfall	June	July	August	September
	----------	---------- cm	----------	----------
At RREC	8.1	9.0	7.9	9.3

[1]Growing season was from 1 June to 30 September.
[2]No pan evaporation data were recorded at DBES.

Plant Growth Measurements

The response of Lee 74 soybean to irrigation during the growing season was determined by monitoring the following plant growth parameters: height, dry weight, leaf area, and root length. Heights of 15 soybean plants in each plot in each replication were measured and averaged at weekly intervals until the R4 growth stage. Aboveground weights of plants were determined from a 46-cm sample randomly chosen from rows prespecified for plant sampling. The plants were then sectioned into leaves, stems, branches and petioles, and pods. Each plant part was dried in an oven for three days at 60 C and weighed to determine dry matter. Leaf area was determined from several plants at two-week intervals using a leaf-area meter. The cumulative leaf area within a 46-cm section of row was divided by the ground area of the row section to obtain the leaf-area index (LAI). Data from dry matter and leaf area were collected during the three growing seasons only from soybeans under the I and N treatments at the two locations to delineate major differences in plant growth (10).

Root lengths were determined on one date in 1974 and on four dates in 1975. Duplicate cores of soil 10 cm in diameter were taken by hand from both the I and N plots to the 100-cm depth at 12.4-cm intervals in the row and in the row middle. The soil samples were brought to the laboratory, dispersed with Calgon and washed through a 40-mesh sieve. The soybean roots were removed from the screen, stained with safarin dye, placed in a petri dish and photocopied. Root length was determined using Newman's line-intersection technique (8). Values of these root lengths were divided by the core volume to give values of root density. Because of the variability of root data using the soil-core method and lack of significant differences between irrigation treatments, the data on root length of soybeans from the I and N moisture treatments were combined.

Plant Water Status

The water status of the Lee 74 soybean was evaluated by measuring the xylem pressure potential (U_l) with a pressure bomb and by measuring the osmotic potential (U_o) with a Peltier-effect psychrometer. The magnitude of these water potentials is indicative of the energy with which water is held by the soybean leaves. The measurements were made on the upper-most, fully developed, sun-exposed, mainstem trifoliolate leaf beginning during late vegetative growth. Measurements were made at frequent but irregular intervals on relatively clear days. Determinations of U_l and U_o were made either at pre-dawn or at midday around 2 p.m. or diurnally—beginning before sunrise and continuing hourly until sunset.

RESULTS AND DISCUSSION

Growth and development of the Lee 74 soybean during the three growing seasons were characterized by the plant's dry weight, height and leaf area at selected dates and by seed yields at harvest. The influence of rainfall, temperature and soil-moisture treatment on growth parameters, water status and seed yield are discussed for each growing season.

1974 Results

Frequency of rainfall and distribution of air temperatures are presented in Figures 1 and 2. Rainfall totals from 1 June to 30 September, 1974, were 69.6 cm and 56.6 cm at DBES and RREC, respectively. The long-term mean rainfall at RREC during these same four months was 34.3 cm. In every month of the 1974 growing season, rainfall exceeded the long-term monthly mean. Rainfall events exceeding 2.5 cm occurred eight times at DBES and seven times at RREC. This substantiates that the 1974 growing season was wetter than normal and indicates that severe water stresses were unlikely in the N plots. At both locations the I plots were irrigated twice during the growing season. At DBES the dates for the I treatment were 9 July and 6 August; at RREC the dates were 8 and 28 August. The B-treatment plots were irrigated on 6 August at DBES and on 14 August at RREC.

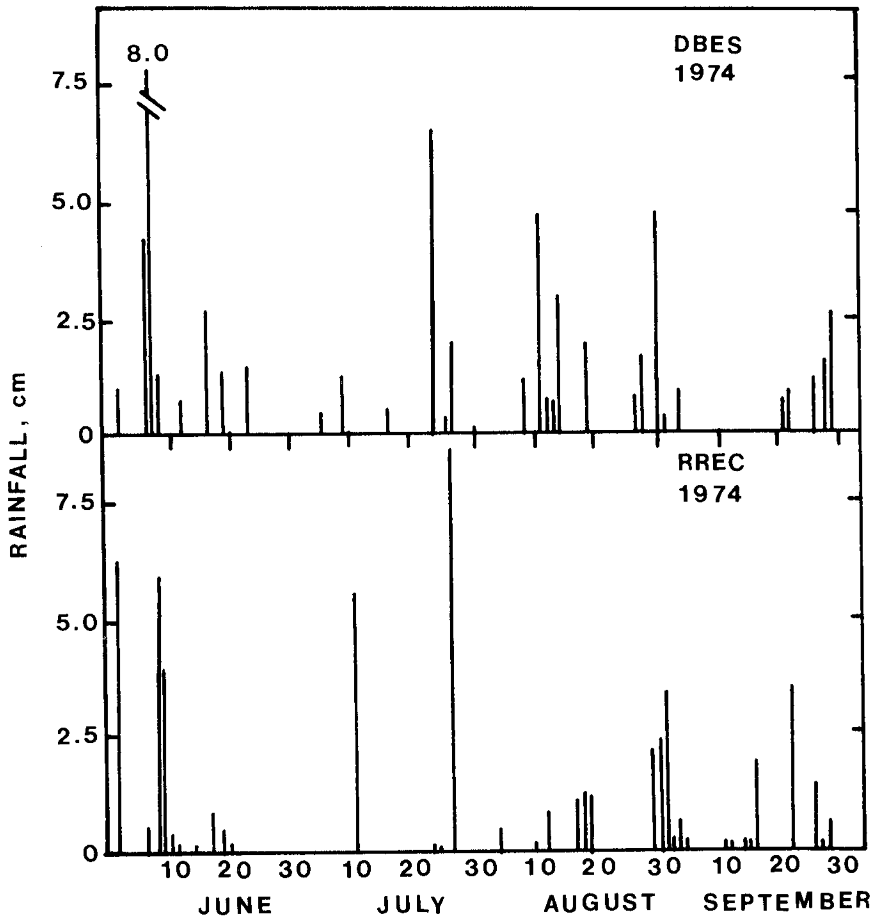

Figure 1. Seasonal rainfall distributions at DBES and RREC, 1974.

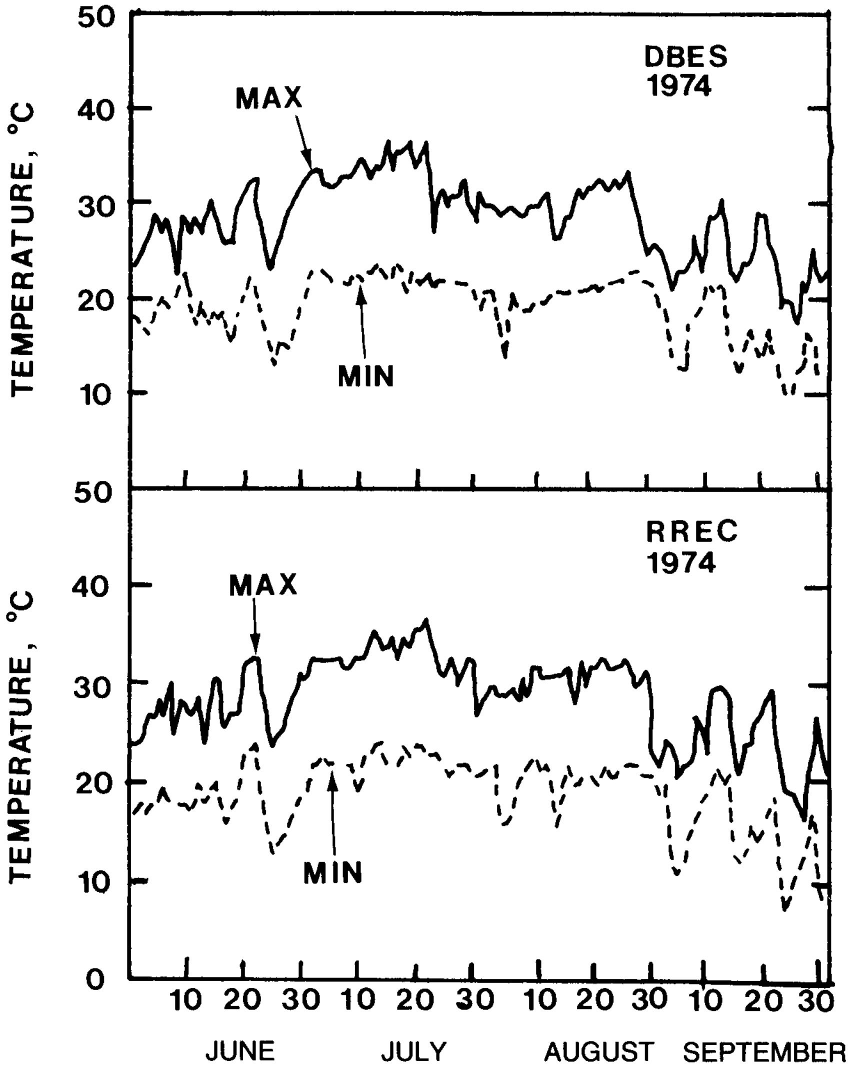

Figure 2. Seasonal maximum and minimum air temperatures at DBES and RREC, 1974.

The mean daily air temperature during July was greater than in August and September at both locations. The monthly mean air temperatures during the 1974 growing season, however, were slightly lower than normal.

The growth and development of Lee 74 soybean in the I and N plots during the 1974 growing season are presented in Figures 3 and 4. Irrigation had little effect on plant growth parameters. By 19 September at DBES the height, dry weight and

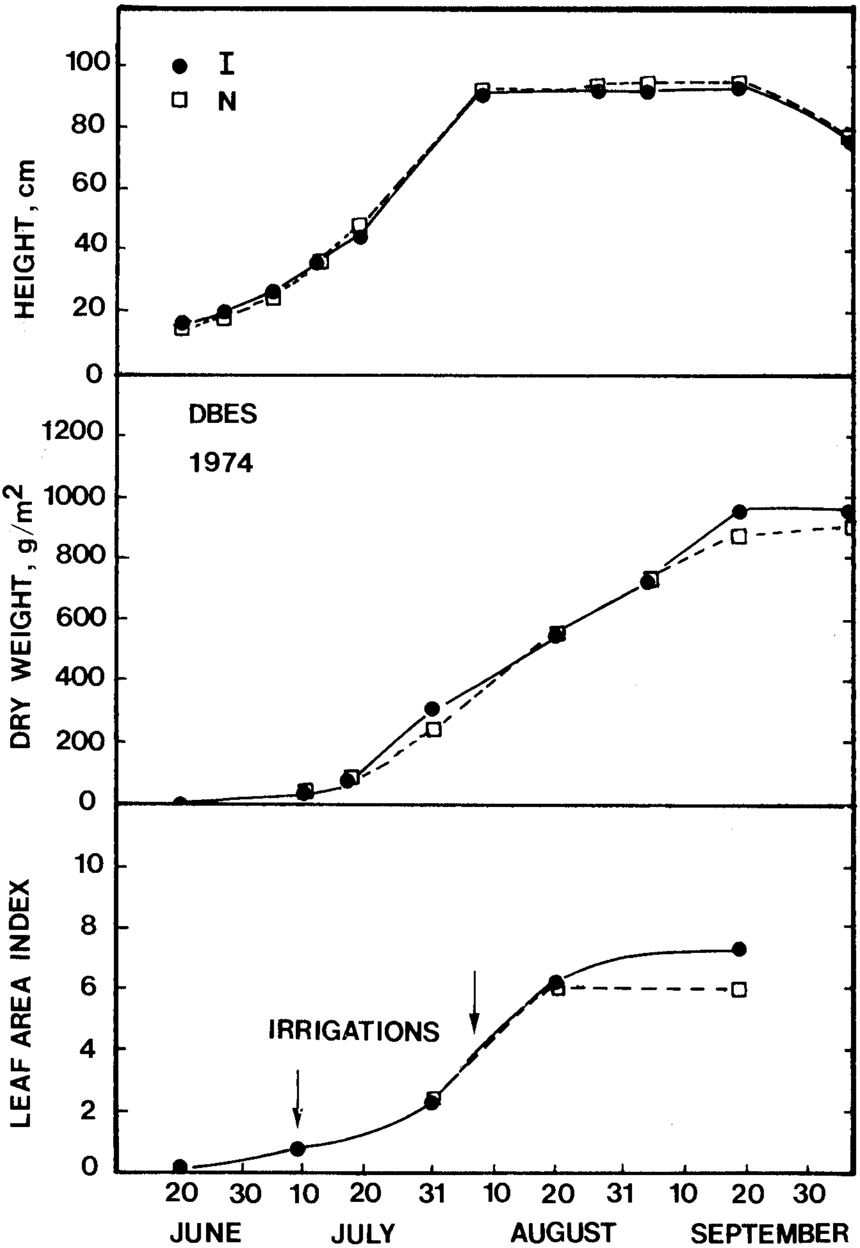

Figure 3. Height, dry weight, and leaf area index of the irrigated (I) and nonirrigated (N) Lee 74 soybean grown at DBES, 1974.

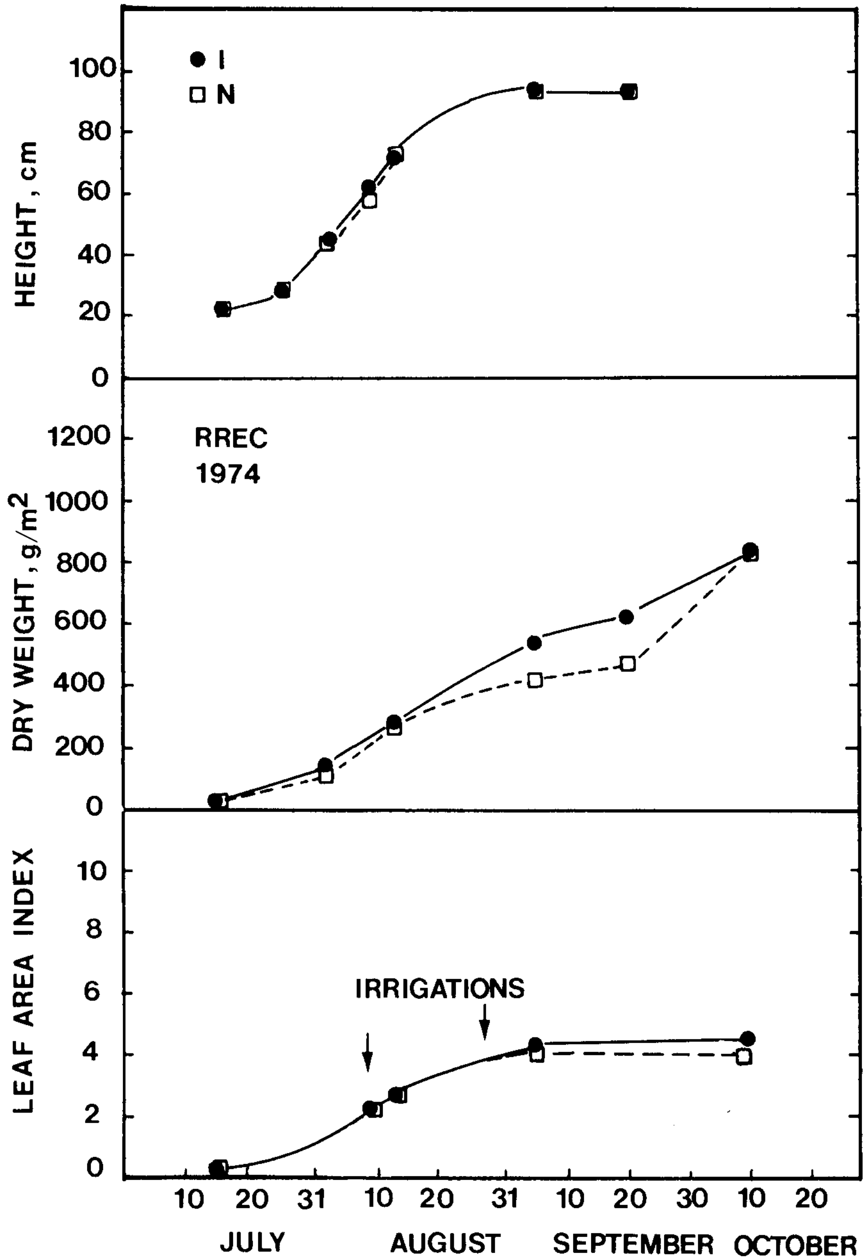

Figure 4. Height, dry weight, and leaf area index of the irrigated (I) and nonirrigated (N) Lee 74 soybean grown at RREC, 1974.

LAI of soybeans from the I plot were 94 cm, 954 g/m^2 and 7.4 m^2/m^2, respectively. These growth parameters were similar to those obtained from the N plot on the same date—95 cm, 872 g/m^2 and 6.1 m^2/m^2, respectively. At RREC the development of the soybeans was somewhat delayed because of late planting. By 20 September the cumulative height, dry weight and LAI of soybeans from the I plot were 94 cm, 626 g/m^2 and 4.4 m^2/m^2 compared to 94 cm, 469 g/m^2 and 4.0 m^2/m^2, respectively, for soybeans from the N plot. The effect of irrigation at both locations was apparently negated by rainfall that followed shortly after the scheduled I treatment.

Soybean root-density distributions to the 100-cm depth were taken on 20 August at DBES and on 13 August at RREC when the soybeans were in the R4 and R2 growth stages, respectively. Profile root distributions at three distances from the row are shown in Figures 5 and 6. Cores were taken in the row over the stump of an excised soybean plant and again at 15 cm and 30 cm from the row. Root densities were highest in the row and in the depth interval of 0 to 12.5 cm. Root density generally decreased with depth in the soil profile. The total profile root length found in the depth interval of 0–12.5 cm was 67.5, 61.4 and 33.5 percent at the 0-, 15- and 30-cm locations on the Kobel clay and 64.5, 58.4 and 63.0 percent at the same locations on the Crowley silt loam. Profile root density generally decreased with distance from the row. The results indicate that the majority of the Lee 74 soybean roots were located between 0 and 31 cm of the soil profile, and that the greatest proportion of Lee 74 soybean roots was found in the row underneath the plant.

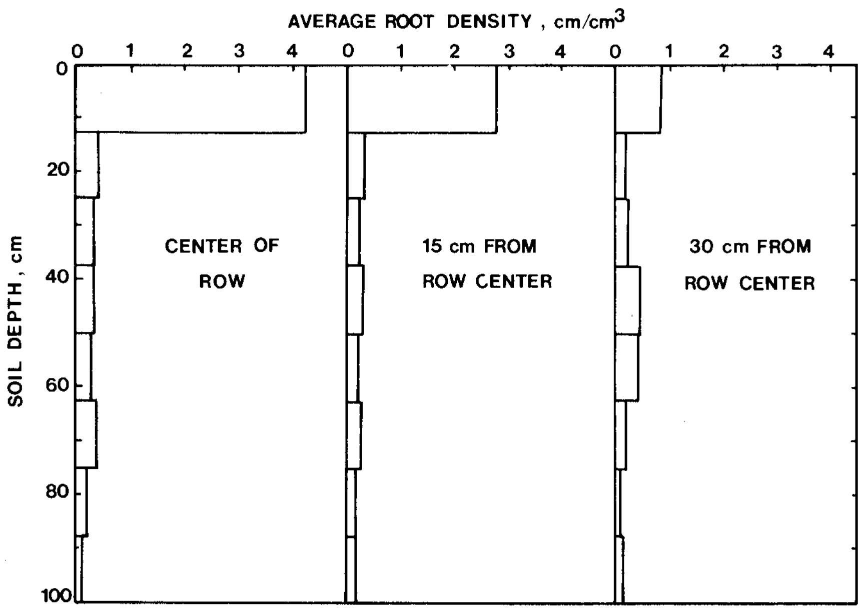

Figure 5. Average soybean root density at three positions from the row as a function of depth in the Kobel clay.

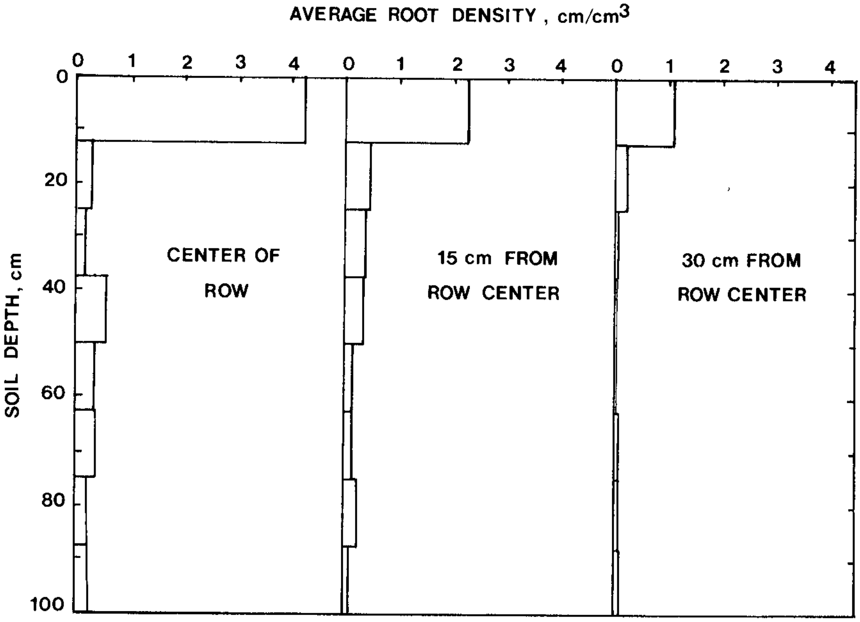

Figure 6. Average soybean root density at three positions from the row as a function of depth in the Crowley silt loam.

Seasonal soil water pressures at the 30- and 122-cm depths in the I and N plots are shown in Figures 7 and 8. Because of the slow redistribution rates of water in these soils, the response of the 30-cm tensiometers to irrigation was delayed as much as two days. When compared with responses found at the 122-cm depth, the soil water pressures at the 30-cm depth were more dynamic. The pressures at 30 cm were influenced to a greater extent by losses of water by plant extraction, movement of water to other depths, and additions of water by rainfall and irrigation than pressures at 122 cm.

At DBES the soil water pressures at the 30-cm depth did not exceed -620 cm in the N plot. The soil water pressures indicate that the soybeans in the N plots were not substantially stressed for water. As evidenced by the decrease in soil water pressure, extraction of water at the 122-cm depth by soybeans in the N plot was initiated by 1 August. For soybeans in the I plot significant extraction of water at the 122-cm depth was initiated by 10 August. The later initiation of water extraction in the I plots indicates that the irrigations on 9 July and 6 August caused the soybean to delay extraction of water at the deeper soil depths.

A comparison of the soil water pressures at the 15-cm depth of the Kobel clay at three distances from the row is shown in Figure 9. The soil water pressures were averaged over all treatments until the LAI of the Lee 74 soybean was approximately 1.0. The soil water pressures that result from water moving up or down in the profile

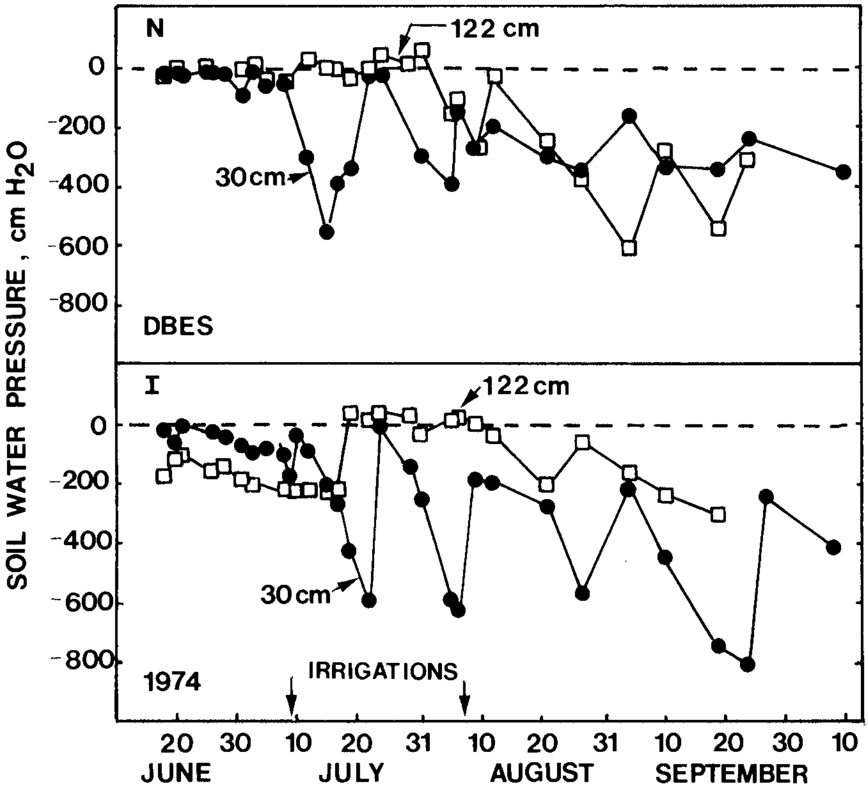

Figure 7. Seasonal soil water pressures at the 30- and 122-cm depths in the irrigated (I) and nonirrigated (N) plots on the Kobel soil during the 1974 growing season.

or from extraction by roots decreased until 18 July. Soil water pressures found at the 0- and 15-cm distances were similar to one another. Soil water pressures at the 30-cm distance, however, tended to be higher than those at 0- and 15-cm distances and to lag behind those closer to the row. Since the movement of water in the unsaturated Kobel clay is slow because of the soil's small pores, the slow root development at this distance resulted in a delay in the extraction of water. The results indicate that early in the growing season and before canopy cover has been established, the decrease in soil water pressure, and therefore, soil water content across the row near the soil surface, is not uniform.

At RREC the dynamic nature of the soil water pressures at the 30- and 122-cm depths was also observed (Fig. 8). At the 122-cm depth positive pressures were measured until 9 August and 29 August on the N and I plots, respectively. This indicates that a water table existed in the Crowley soil, and that extraction of water by the soybean roots at the 122-cm depth did not occur until reproductive growth had begun. The later initiation of extraction of soil water at the 122-cm depth in the

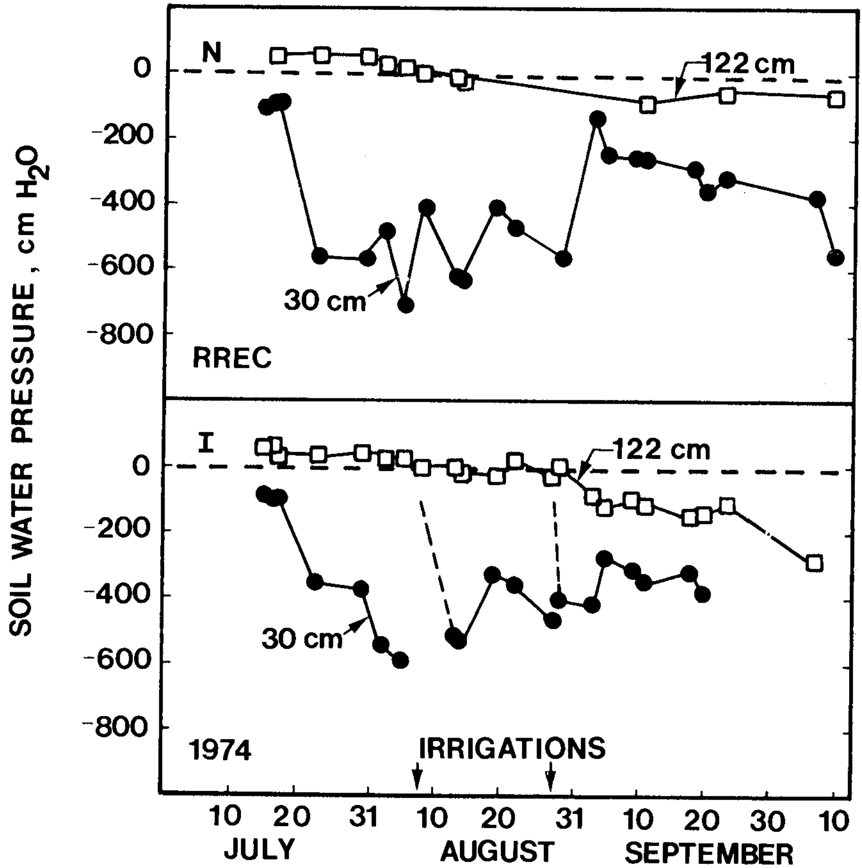

Figure 8. Seasonal soil water pressures at the 30- and 122-cm depths in the irrigated (I) and nonirrigated (N) plots on the Crowley soil during the 1974 growing season.

I plots can be attributed to the plant's use of irrigation water stored in the upper parts of the profile near the soil surface in preference to soil water at the lower portions of the profile. On both soils soybeans in the I plots were slow to utilize water at the 122-cm depth.

The dynamic nature of soil moisture contents at shallow depths in the row was determined over a 12-hour period on 13 August on the Crowley soils. Hourly measurements of gravimetric soil water contents were taken in the I and N plots five days after the I plots were irrigated. The results show that the soil water content was highest in the I plot and fluctuated considerably during the day (Fig. 10). The greatest changes in water content occurred at the depth interval of 0 to 2.5 cm and in the I plot. This was primarily because of evaporation from the soil surface. Generally, the lowest soil water content at the surface was found at 5:00 p.m. and

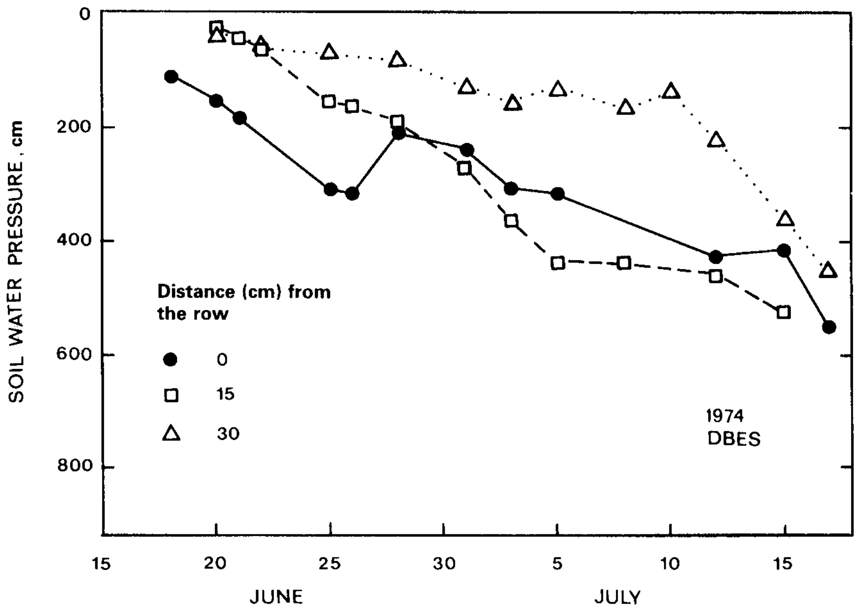

Figure 9. Average 15-cm depth water pressures at three positions from the row in the Kobel soil.

at later times for the lower depths. Late in the day soil water content in the depth interval of 0 to 2.5 cm began to increase. The data indicate that soil water content oscillations near the surface were damped with depth in a manner similar to that of soil temperature.

Seed yields of the soybeans grown at the two locations in 1974 are given in Table 5. No response to irrigation was found at either location. At DBES the average yield was a relatively low 1671 kg/ha; this low yield was because of the preharvest shattering and high combining losses associated with the late harvest in January 1975.

Table 5. Three-year summary of seed yields for Lee 74 soybean as affected by irrigation treatment.

Location	Moisture Treatment	Seed Yield* 1974	1975	1976	Average* Yield	Percent Increase
		---------- kg/ha	----------	----------		
DBES	I	1626 a	2903 a	2789 a	2439 a	49.4
	B	1667 a	2177 b	1908 b	1917 b	17.4
	N	1720 a	1600 c	1579 b	1633 c	
RREC	I	2735 a	2890 a	3044 a	2890 a	39.7
	B	2869 a	1942 b	2439 b	2417 b	16.9
	N	2715 a	1875 b	1613 c	2068 c	

*Yields with the same letter within a year and at a location are not significantly different at the 0.05 probability level.

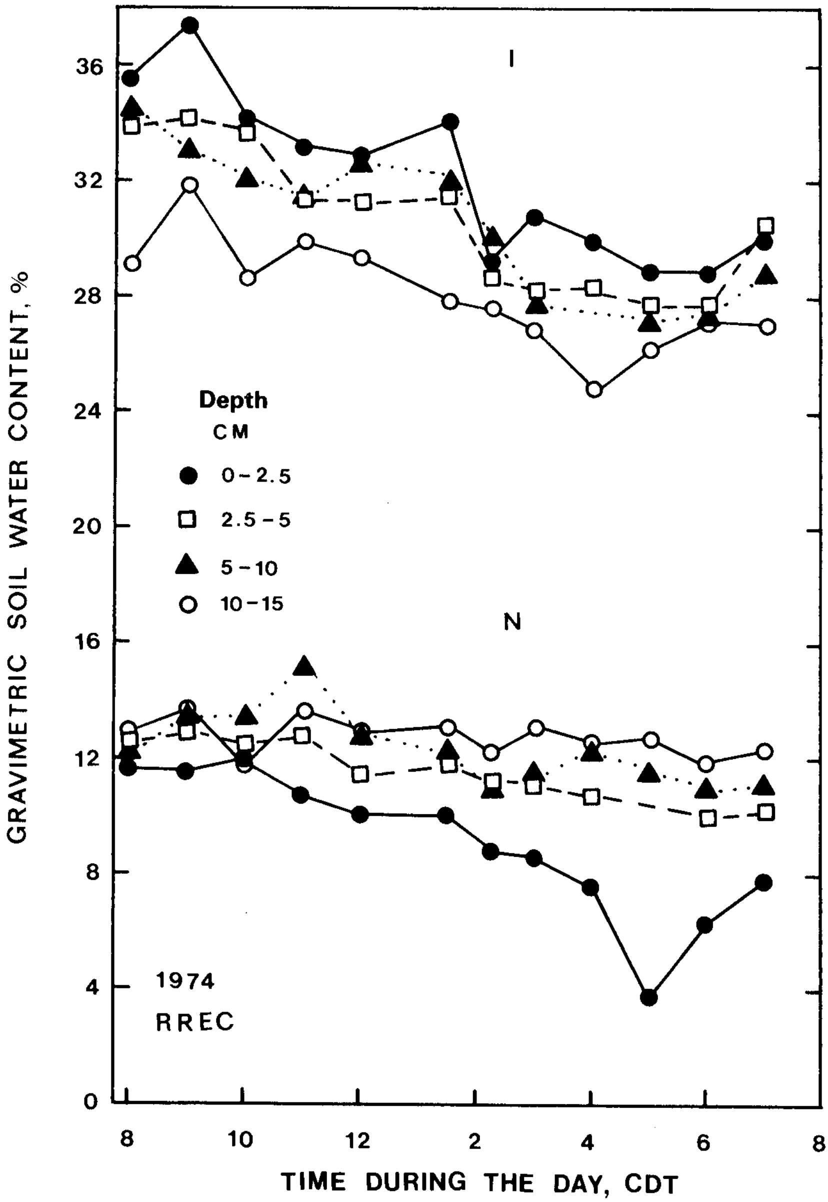

Figure 10. Gravimetric soil moisture contents at four depths of the Crowley soil, 13 August 1974.

At RREC the average yield was 2773 kg/ha, which is thought to be near the maximum yield under favorable conditions for this cultivar when grown on the Crowley soil.

1975 Results

The daily rainfalls and air temperatures during the 1975 growing season at both locations are presented in Figures 11 and 12. When compared to the long-term means, the seasonal cumulative rainfall between 1 June and 30 September was 14.3 cm below normal at DBES and 4.5 cm below normal at RREC. A seasonal rainfall total of 20.0 cm was recorded at DBES, and 29.8 cm was recorded at RREC. At DBES, rainfall during June (4.8 cm), July (2.9 cm) and August (2.8 cm) was considerably lower than normal. Similarly, rainfall at RREC during July (4.2 cm) and September (2.8 cm) was lower than normal. The rainfall amounts at both locations were considerably less than the pan evaporation observed at RREC. This indicates that the plants may have experienced severe stress, although drought stress may differ with plant age, location, and soil. The seasonal air temperatures were close to normal.

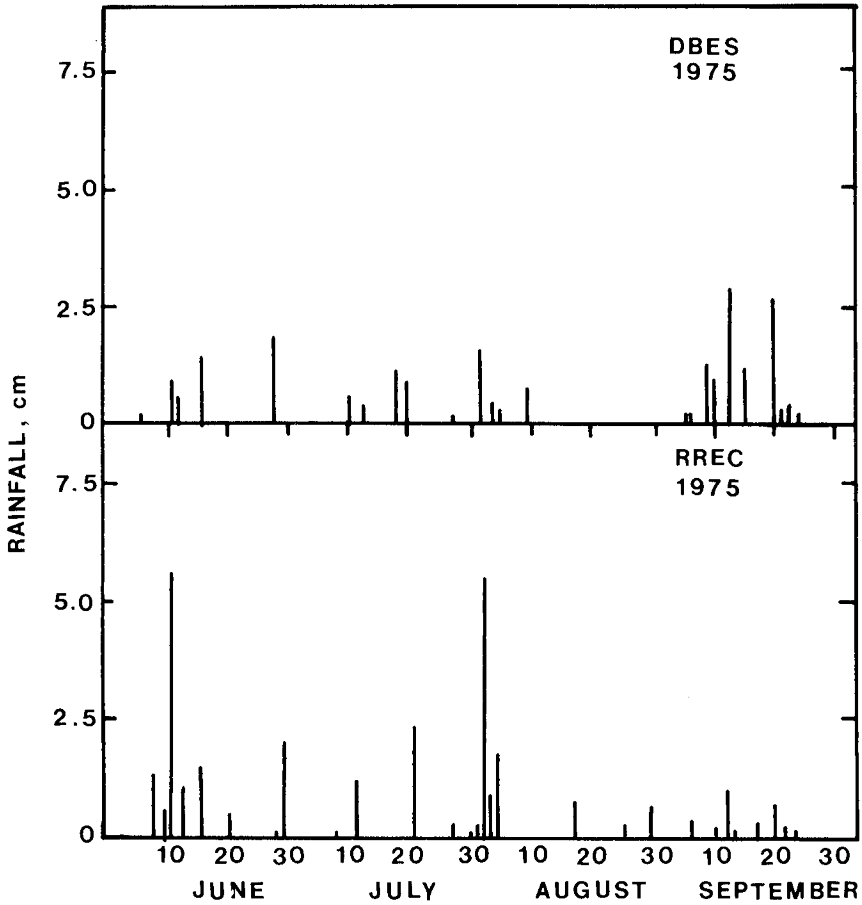

Figure 11. Seasonal rainfall distributions at DBES and RREC, 1975.

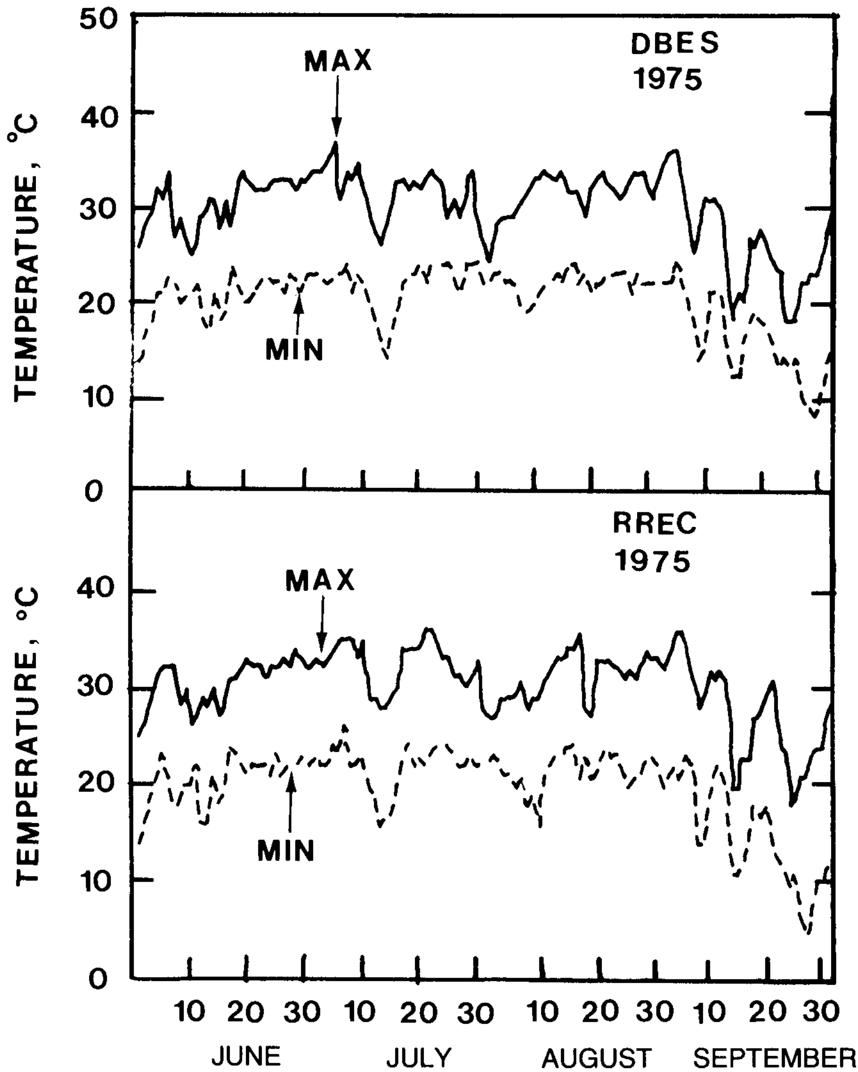

Figure 12. Seasonal maximum and minimum air temperatures at DBES and RREC, 1975.

Growth and development of Lee 74 soybean during the 1975 growing season are presented in Figures 13 and 14. These results show that significant differences in plant growth occurred between soybean in the I and N plots at both locations. These differences occurred during late July and early August when the soybean were in the late vegetative to bloom growth stages. By 5 August, when the soybeans were in the R1 growth stage, the soybean in the I plots at both locations were taller, had greater dry weight and more leaf area than soybeans from the N plots. Soybean in

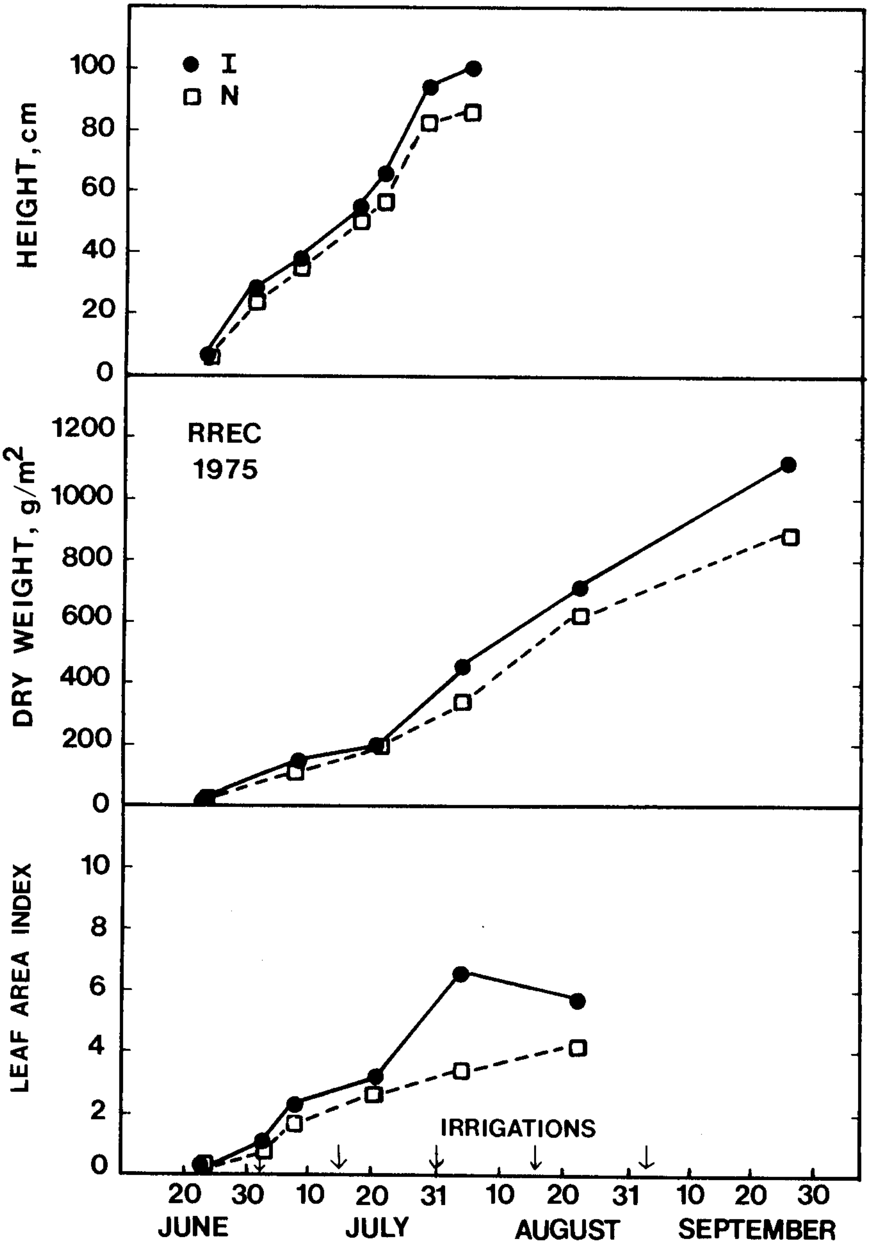

Figure 13. Height, dry weight, and leaf area index of the irrigated (I) and nonirrigated (N) Lee 74 soybean grown at RREC, 1975.

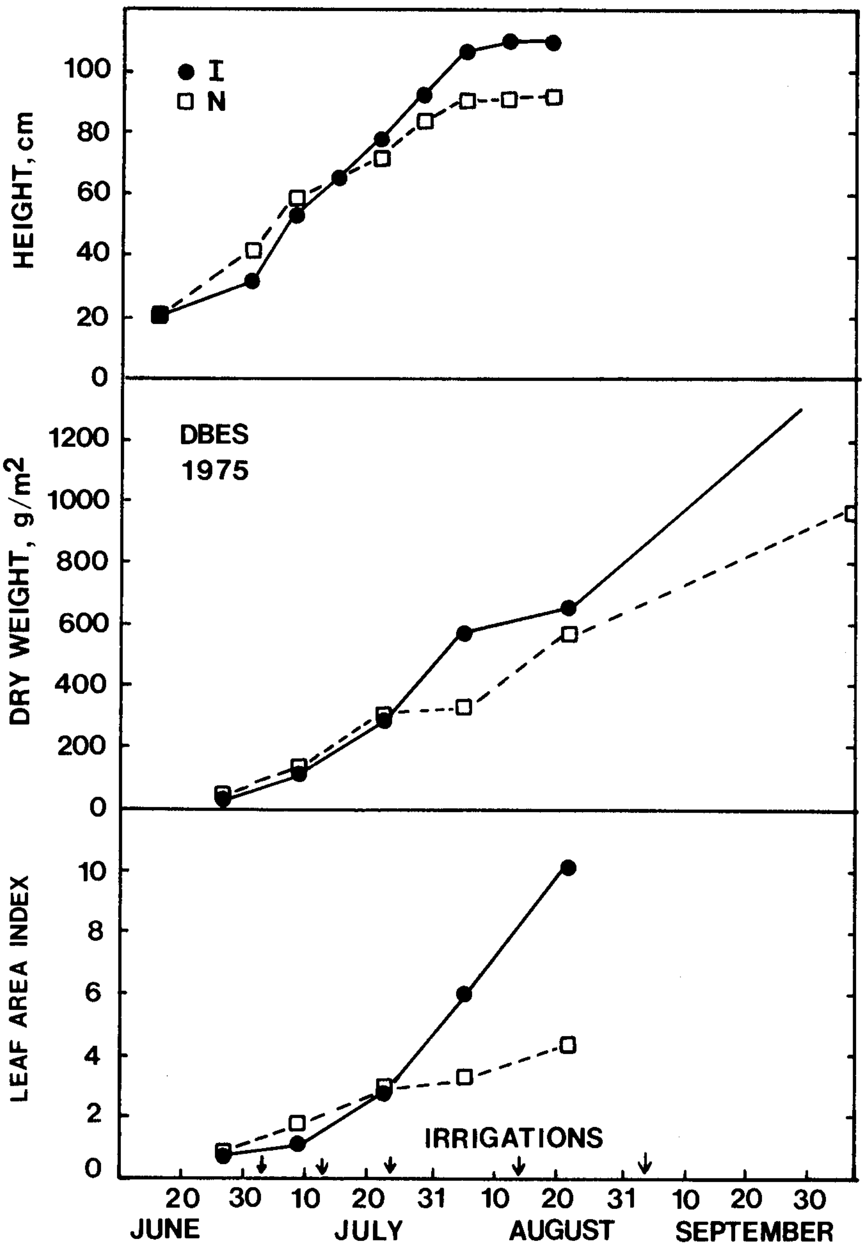

Figure 14. Height, dry weight, and leaf area index of the irrigated (I) and nonirrigated (N) Lee 74 soybean grown at DBES, 1975.

the I plots were irrigated at DBES on 3, 11 and 24 July, on 14 August and on 4 September and at RREC on 2, 15 and 31 July, on 17 August and on 3 September. The B plots were irrigated on 6 August at DBES and on 31 July at RREC.

The water status of soybeans from the I and N plots was quantitatively characterized by measuring the xylem water pressure potential and osmotic potential as affected by irrigation and climate. The experimental data collected were divided into three categories: seasonal midday observations, seasonal pre-dawn (or recovery) observations, and periodic diurnal observations. The seasonal midday observations were conducted at both DBES and RREC, whereas the pre-dawn and diurnal data were collected only at RREC. Physically, xylem pressure potential, U_l, represents the amount of pressure existing on water that is present in the xylem of the plant. Its meaning is directly analogous to soil water pressure potential although the xylem pressure potential is considerably more dynamic in nature. Values of leaf osmotic potential, U_o, are associated with the concentration of solutes in the plant protoplasm. As with soil water matric potential, the values of U_l and U_o become more negative as water stress increases.

Seasonal values of pan evaporation and pre-dawn U_l and midday U_l for soybeans in the I and N plots at RREC are presented in Figure 15. Irrigation dates are indicated with arrows. No significant differences in U_l were found between irrigation treatments except perhaps for very short periods immediately following an irrigation and late in the growing season when prolonged dry weather occurred. Seasonal average values of midday U_l were -13.3 bars for soybeans under the I treatment and -14.0 bars for soybeans under the N treatment. The results indicate that few significant differences existed in midday U_l that could be attributed to irrigation.

As reported by Sojka et al. (13) there was a highly significant inverse correlation between the observed midday U_l and pan evaporation. The correlation varied between plant growth stage and soil moisture treatment. Pan evaporation, which is a measure of evaporative demand, had a greater effect on U_l in the I plot than in the N plots, and it had a greater effect during reproductive stages than during the vegetative stages. This indicates that soybeans in the I plots were more responsive to the daily variations in environmental evaporative demand. Pre-dawn observations of U_l indicate that by midpodfill soybeans in the N plots failed to recover to the maximum U_l values found in the I plots. The seasonal average pre-dawn U_l values were -2.0 and -3.3 bars for soybean in the I and N plots, respectively. These lower values of U_l in the N plots result from drought stress.

Diurnal variations in U_l and U_o for soybeans in the I and N plots at RREC are presented in Figure 16. A summary of the air temperatures and soil water pressures for 22 July, 12 August and 10 September is presented in Table 6. It is of interest to compare the rates of decline in water potential, duration of depressed water potentials and rate of recovery of soybeans in the I and N plots. The first diurnal study was conducted on 22 July, seven days after an irrigation, when the soybean were in the V12 growth stage. A reduction of approximately 12 bars xylem pressure was recorded between 6:00 a.m. and 2:00 p.m. Recovery began to occur by

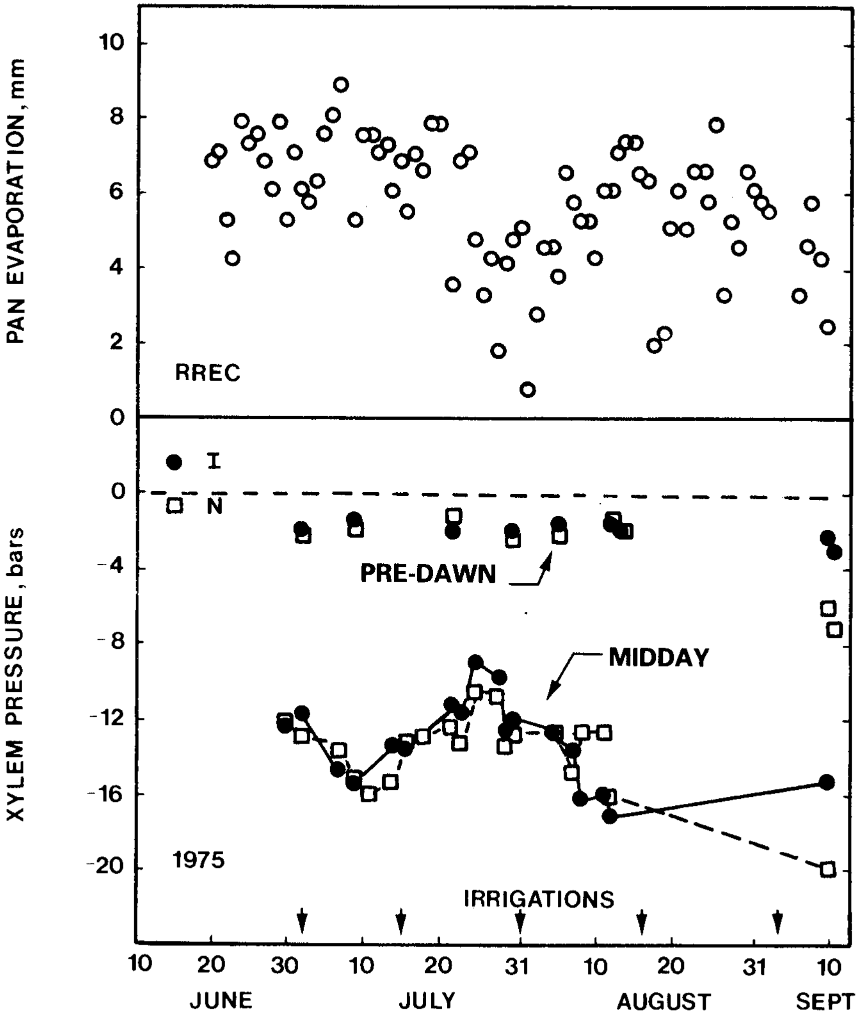

Figure 15. Values of the pre-dawn and midday xylem pressures of the irrigated (I) and nonirrigated (N) soybean and pan evaporation at RREC, 1975.

approximately 5:00 p.m. and was complete by 8:00 p.m. A small diurnal shift occurred in U_o. The 12 August diurnal data were taken at flowering, two weeks after an irrigation. Again the treatment differences were not significant, indicating that by two weeks following an irrigation, water movement to the soybean roots in the I plots was restricted. As a result, similar values of U_l were found. On 12 August, the pressure difference due to diurnal effects was 17 bars for a midday minimum U_l of − 19 bars. Night recovery did not begin until about 6:00 p.m., one hour later than the 22 July recording. On 10 September, the soybean were in

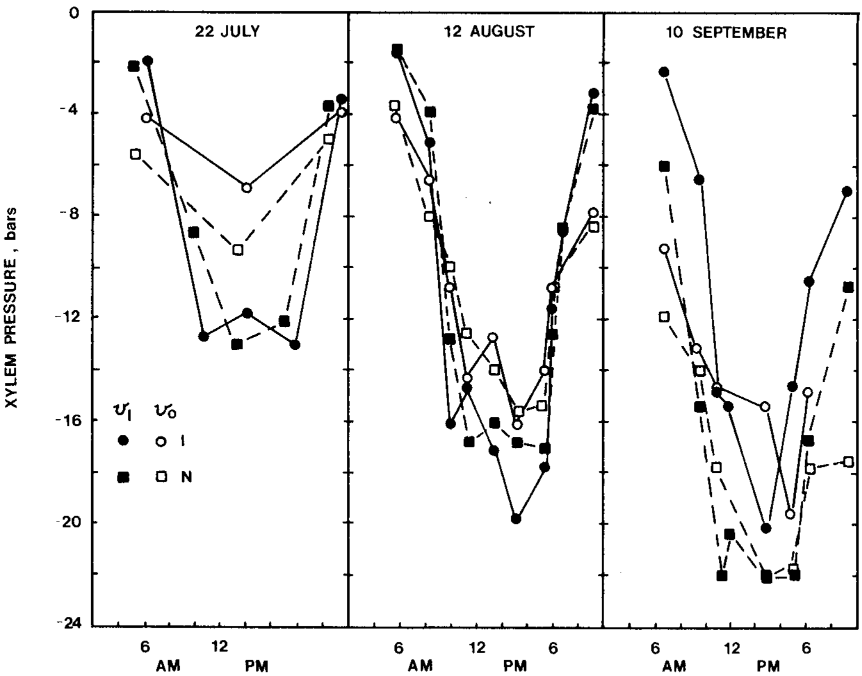

Figure 16. Diurnal variation of xylem pressure potentials and osmotic potentials on irrigated (I) and nonirrigated (N) soybean during three days of the 1975 growing season.

Table 6. Summary of the air temperatures, pan evaporation, and soil water pressures at three soil depths during the diurnal plant water studies for full-season irrigation (I) and no irrigation (N) at RREC, 1975.

	Air Temp.		Pan	Soil Water Pressure[1]					
				I			N		
Date	Max.	Min.	Evap.	15cm	30cm	45cm	15cm	30cm	45cm
	C	C	cm	cm					
22 July	36	23	0.69	−312	−427	−383	---	−318	−397
12 Aug.	33	24	0.66	−307	−377	−453	---	---	---
10 Sept.	31	22	0.51	−782	−658	−324	---	---	---

[1]All spaces without data had no soil water matric pressures below the working range of tensiometers (ie., −850 cm of water).

midpodfill, and the diurnal shift in U_l was about 17 bars. The U_l of soybean in the N plots decreased earlier in the day and recovered later in the afternoon when compared with soybean from the I plots. Soybean from the N plots never recovered to the same level as those from the I plots. A consistent difference of about 4 bars was retained between treatments throughout the day. Minimum U_l in soybean in the N plots had decreased to −24 bars. The measurements followed irrigation in the I plots by one week and indicate the stressed conditions of soybean in the N plots.

Seasonal values of midday U_l for soybeans from the I and N plots at DBES are presented in Figure 17. Midday values of U_l ranged from -4.0 bars on 5 August to -18.5 on 16 July. Seasonal averages of U_l were -12.0 and -13.9 bars for I and N plots, respectively. The magnitude of these U_l values are similar to those observed at RREC (Fig. 15). The results indicate that the Lee 74 soybean grown under N conditions were stressed to a greater extent than soybean grown under I conditions, and the stress became more severe as the drought progressed.

In 1975, soybean root distributions were determined four times during the growing season. Core samples were taken in the row and in the row middle. Statistically, there were no differences because of irrigation; therefore, the data were combined. The results, presented in Table 7, represent the averages of four determinations taken in the row and two determinations taken in the row middle. As in the previous season, the highest root densities were in the row in the depth increment of 0 to 12.5 cm. On the Crowley silt loam the highest root density was found in the row on 4 August

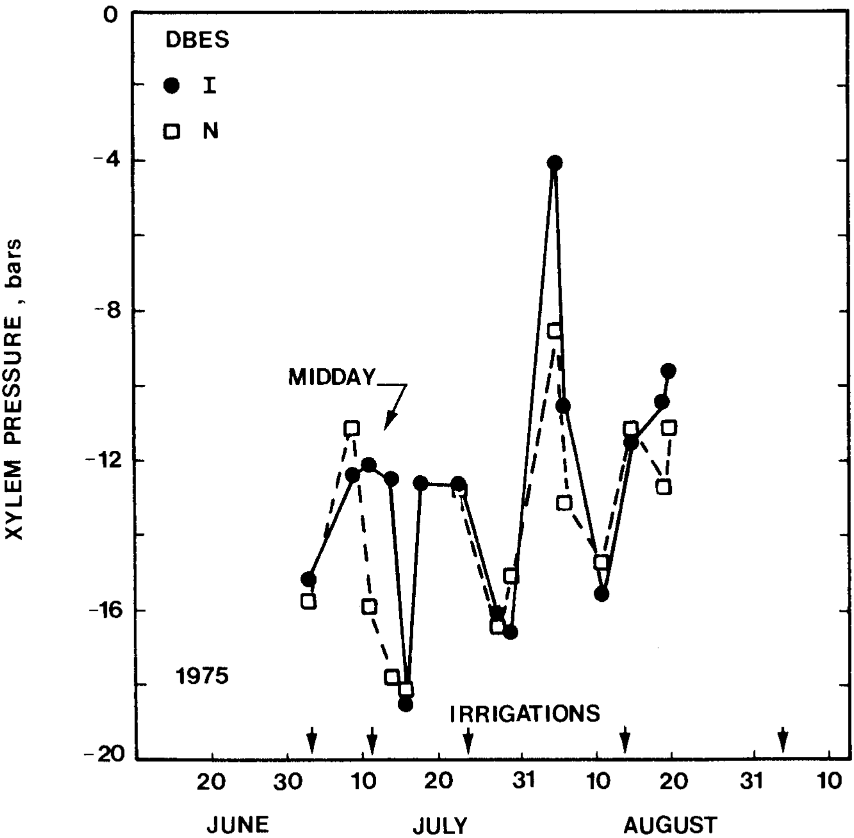

Figure 17. Seasonal values of the midday xylem pressures of the irrigated (I) and nonirrigated (N) soybean at DBES, 1975.

Table 7. Soybean root distributions in the row (R) and in the row middle (M) at four sampling dates during the 1975 growing season.

				Average Root Density Depth Interval (cm)							
Soil	Date	Growth Stage	Row Position	0 to 12.5	12.5 to 25.0	25.0 to 38.5	38.5 to 50.0	50.0 to 62.5	62.5 to 75.0	75.0 to 88.5	88.5 to 100
				(cm/cm³)							
Kobel (DBES)	3 July[3]	V8	R[1]	2.18	0.56	0.33	0.50	0.11	0.26	0.05	0.08
	23 July	V12	R	4.05	0.77	0.49	0.44	0.30	0.25	0.20	0.06
			M[2]	0.31	0.46	0.43	0.38	0.32	0.15	0.12	0.06
	6 August	R2	R	3.30	0.82	0.67	0.41	0.32	0.40	0.25	0.17
			M	0.66	0.57	0.30	0.19	0.06	0.09	0.05	0.12
	10 October	R7	R	2.72	0.78	0.27	0.14	0.16	0.08	0.09	0.08
			M	0.34	0.19	0.11	0.12	0.11	0.09	0.11	0.03
Crowley (RREC)	3 July[3]	V8	R	2.42	0.46	0.19	0.10	0.17	0.17	0.17	0.08
	22 July	V12	R	4.00	0.95	0.46	0.50	0.33	0.38	0.41	0.58
			M	0.50	0.14	0.08	0.05	0.14	0.16	0.16	0.28
	4 August	R1	R	6.64	0.73	0.51	0.29	0.39	0.47	0.48	0.38
			M	1.94	0.64	0.30	0.14	0.06	0.10	0.21	0.29
	7 October	R7	R	4.76	0.71	0.26	0.27	0.39	0.12	0.45	0.34
			M	2.18	0.42	0.22	0.20	0.11	0.05	0.07	0.11

[1]Row = in the row.
[2]M = in the row middle.
[3]Root samples in the row middle were not taken on this date.

and in the row middle on 7 October. In contrast the highest root density in the Kobel clay at DBES was found in the row on 23 July and in the row middle on 6 August. When all root densities were statistically analyzed by depth, the 0- to 12.5-cm depth increment was significantly influenced by location ($P<.05$), position in the row ($P<.01$), and sampling date ($P<.05$). Root densities in this depth increment were higher at RREC than at DBES, and they were higher in the row than in the row middle and higher during early August than at other sampling times. In the depth increment of 12.5 to 25.0 cm, root densities in the row were significantly greater than those in the row middle ($P<.05$). At the deeper depths, the effects of location, irrigation, position in the row, and sampling date were nonsignificant.

The root intensity of the profile was determined by multiplying the incremental root densities by 12.5 and summing over the 100-cm sampling depth. Root intensity gives a quantitative measure of the amount of root present at that position in the profile.

The soybean root intensities on both soils are presented in Table 8. The results show that the profile root intensities increased to a maximum of 123.6 cm/cm^2 on 4 August on the Crowley soil and increased to 82.8 cm/cm^2 on 23 July on the Kobel soil. On the Kobel soil the profile root intensities in the row on 10 October and 3 July were similar to each other. These calculations indicated that the root intensities of the soybean grown on the Crowley silt loam were higher than those on the Kobel clay. Perhaps some of this can be attributed to the closer row spacing and to the higher root density in the 0- to 12.5-cm depth increment of the soybean growing on the Crowley soil. This soil has a distinct plow pan, and under dry conditions it has restricted soybean root development.

The soil water pressures at the 30- and 122-cm depths in the I and N plots are

Table 8. Root intensities as a function of time and position in the row, 1975.

Soil	Date	Row Position[1]	Root Intensity
			cm^2/cm^3
Kobel	3 July[2]	R	50.9
(DBES)	23 July	R	82.0
		M	27.9
	6 August	R	79.3
		M	25.5
	10 October	R	54.0
		M	13.8
Crowley	3 July[2]	R	47.1
(RREC)	22 July	R	95.1
		M	18.9
	4 August	R	123.6
		M	46.0
	7 October	R	91.3
		M	42.0

[1]R = row, M = row middle.
[2]Root samples were not taken in the row middle on this date.

presented in Figures 18 and 19. At DBES the pressures at the 30-cm depth were much more responsive to changes in soil water content caused by the extraction of water by soybean than the pressures at the 122-cm depth (Fig. 18). The magnitude of the pressures at the 30-cm depth varied during the season between −100 and −700 cm of water for the I plots and between −200 cm and some unknown value greater than −850 cm for the N plots. Unknown values result from the fact that the maximum pressure that can be measured with tensiometers is approximately −850 cm of water. The soil water pressures at the 122-cm depth varied between −120 and −430 cm of water in the I plots and between 0 and −530 cm of water in the N plots. The results show that extraction of water at the 122-cm depth by the soybean in the N plots occurred sooner than extraction in the I plots. Drought caused the soybean in the N plots to explore the deeper portions of the soil profile sooner than those in the I plots.

At RREC (Fig. 19) the pressures at the 30-cm depth ranged from −50 cm to −720 cm in the I plots and from −100 cm to some unknown value in the N plots. Similarly, the pressures at the 122-cm depth ranged from 70 to −580 cm of water

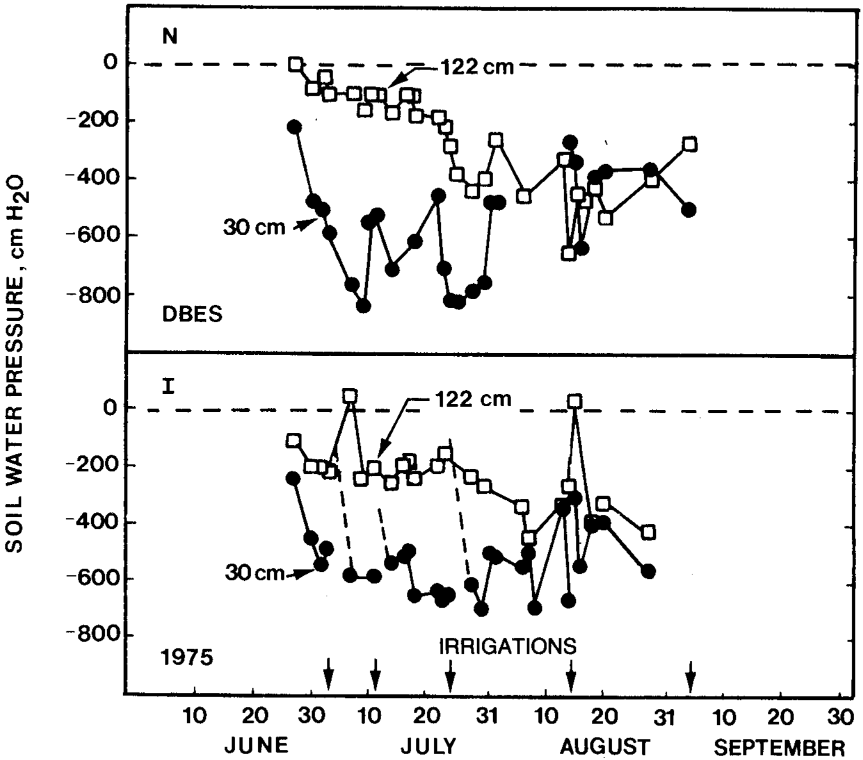

Figure 18. Seasonal soil water pressures at the 30- and 122-cm depths in the irrigated (I) and nonirrigated (N) plots on the Kobel soil during the 1975 growing season.

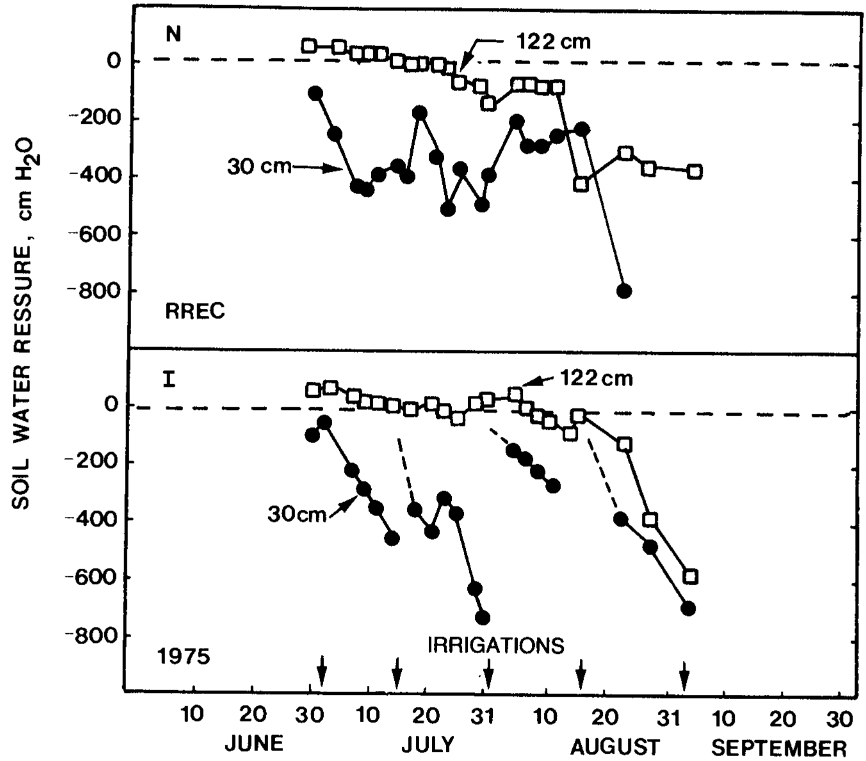

Figure 19. Seasonal soil water pressures at the 30- and 122-cm depths in the irrigated (I) and nonirrigated (N) plots on the Crowley soil during the 1975 growing season.

in the I plots and from 70 to -420 cm of water in the N plots. The positive pressures indicate that a water table was found in the Crowley soil, and that saturated conditions were found at the 122-cm depth until approximately 20 July and 7 August in the N and I plots, respectively. Generally, few differences in water-table depth were observed between the treatments until 18 July (Fig. 20). After this date, differences in the water table depth between the I and N treatments can probably be attributed to the irrigation on 15 July because the depth of rooting was higher than the water table at the time of the irrigation on 3 July. After 23 July the depth of the water table in the N plots was greater than the 137-cm tensiometer. Water table measurements were continued in the I plots until 14 August. The results indicate that the soybean in the I plots responded to the irrigations by delaying significant extraction of water at the lower depths of soil.

The seed yields of the Lee 74 soybean grown in 1975 are presented in Table 5. At DBES yield increases above those of the N plots were 1303 kg/ha and 577 kg/ha in the I and B treatments, respectively. Significant differences in yield were found between all treatments at DBES, indicating that the one irrigation on 6 August was

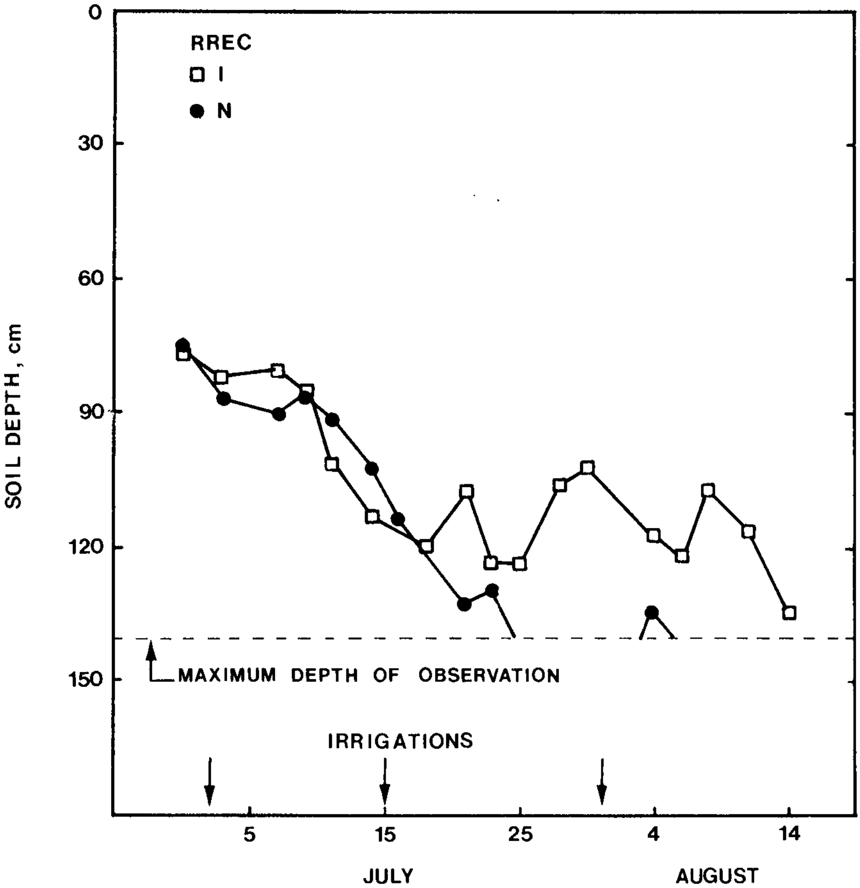

Figure 20. Depth to the water table of the irrigated (I) and nonirrigated (N) plots in the Crowley soil during the 1975 growing season.

significantly better than no irrigation during the season and that a significant yield response was found from the single application of water. The single irrigation was not sufficient, however, to increase the yield of the B soybean to the level of the I soybean. The average seed yield at DBES was 2227 kg/ha.

At RREC, yield increases over yields from the N plots were 1015 kg/ha and 67 kg/ha in the I and B treatments, respectively. The one irrigation at RREC on 31 July was not sufficient to increase seed yields significantly. The average seed yield at RREC was 2236 kg/ha.

1976 Results

The daily rainfall and air temperatures during the 1976 growing season are presented for both locations in Figures 21 and 22. When compared to the long-term mean, the cumulative rainfall between 1 June and 30 September was 4.8 cm below

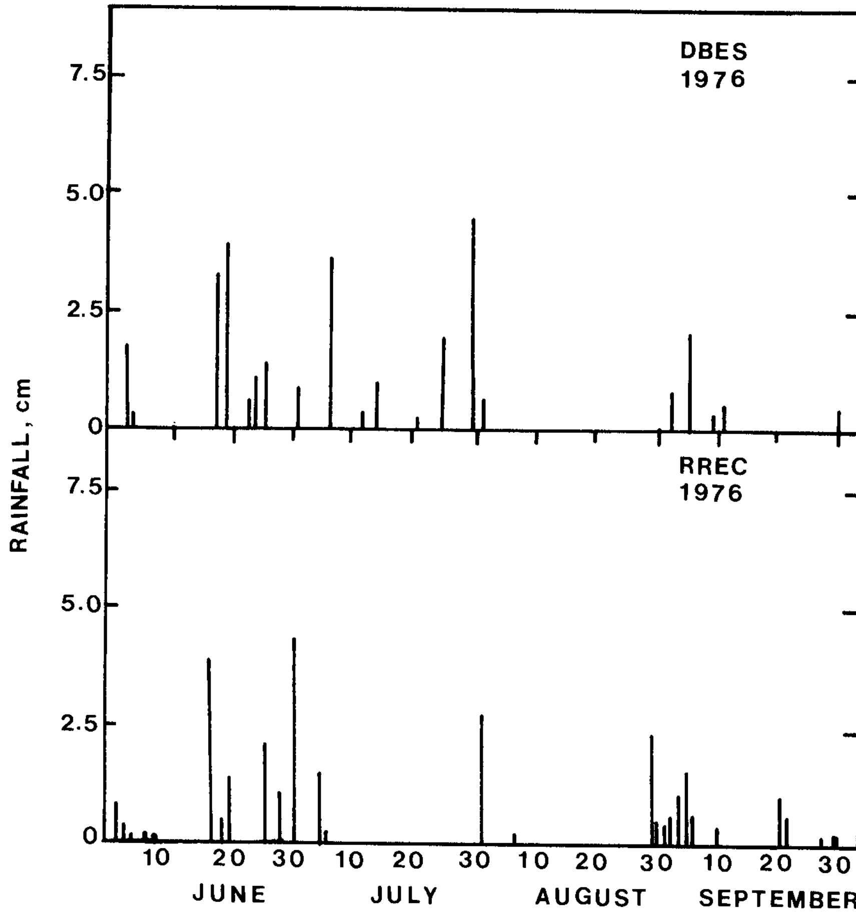

Figure 21. Seasonal rainfall distributions at DBES and RREC, 1976.

normal at DBES and 5.1 cm below normal at RREC. At DBES no rainfall was recorded in August, and only 3.9 cm were recorded in September. At RREC cumulative rainfall during July (4.2 cm), August (3.0 cm) and September (6.8 cm) was lower than normal. Severe water stresses developed during the 1976 growing season, and the soybeans grown at RREC were exposed to drought earlier than soybean at DBES.

The response of Lee 74 soybean to the water management treatments in 1976 (Figs. 23 and 24) was similar to that found during the 1975 growing season. The soybean in the I plots accumulated greater dry weight, height and leaf area than the soybean in the N plots, primarily during the reproductive growth stages. At RREC the irrigation dates for the I plots were 19 and 26 July, and 5, 10 and 20 August. The irrigation dates for the B plots were 29 July and 5 and 10 August. At DBES

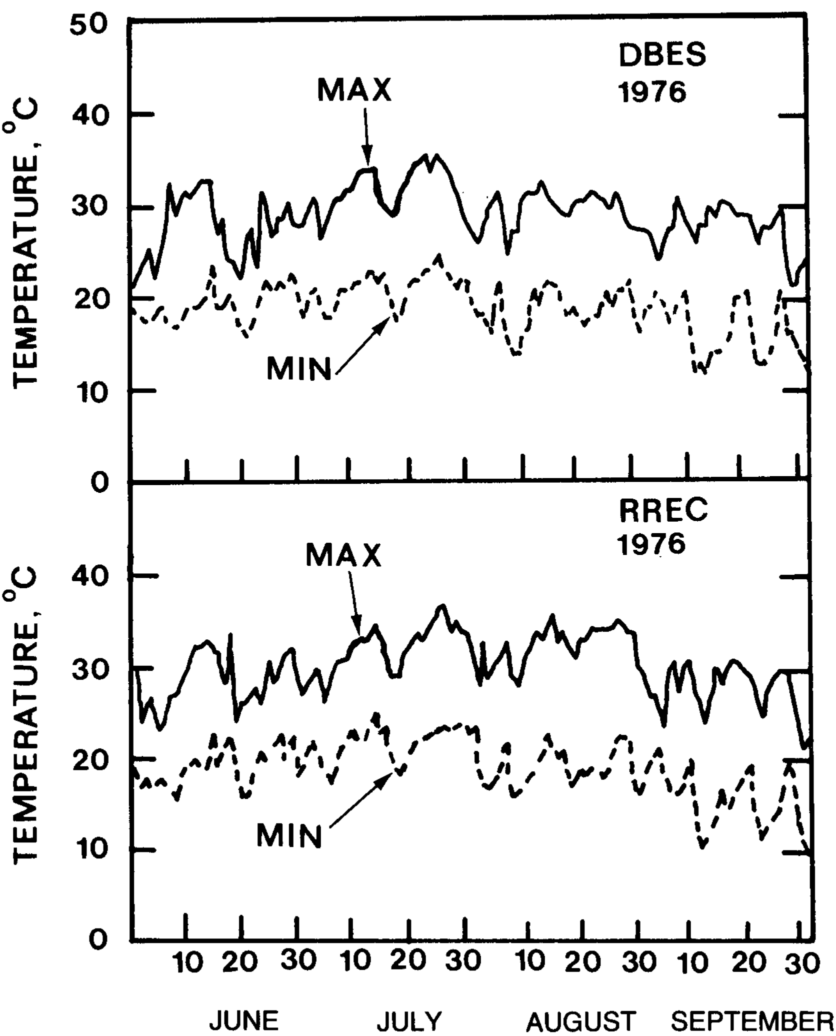

Figure 22. Seasonal maximum and minimum air temperatures at DBES and RREC, 1976.

the irrigation dates for the I plots were 21 and 29 July, 11 and 20 August and 14 September. The irrigation date for the B plots was 9 August.

At DBES significant differential growth because of soil moisture treatment was initially found on 18 August (Fig. 23). When compared with the soybean from the N plots on this date, the soybean from the I plots were only 2 cm taller, but they had accumulated 200 g/m^2 more dry weight and 1.0 m^2/m^2 more leaf area. These differences in plant growth can be attributed to the irrigations applied during late July and early August.

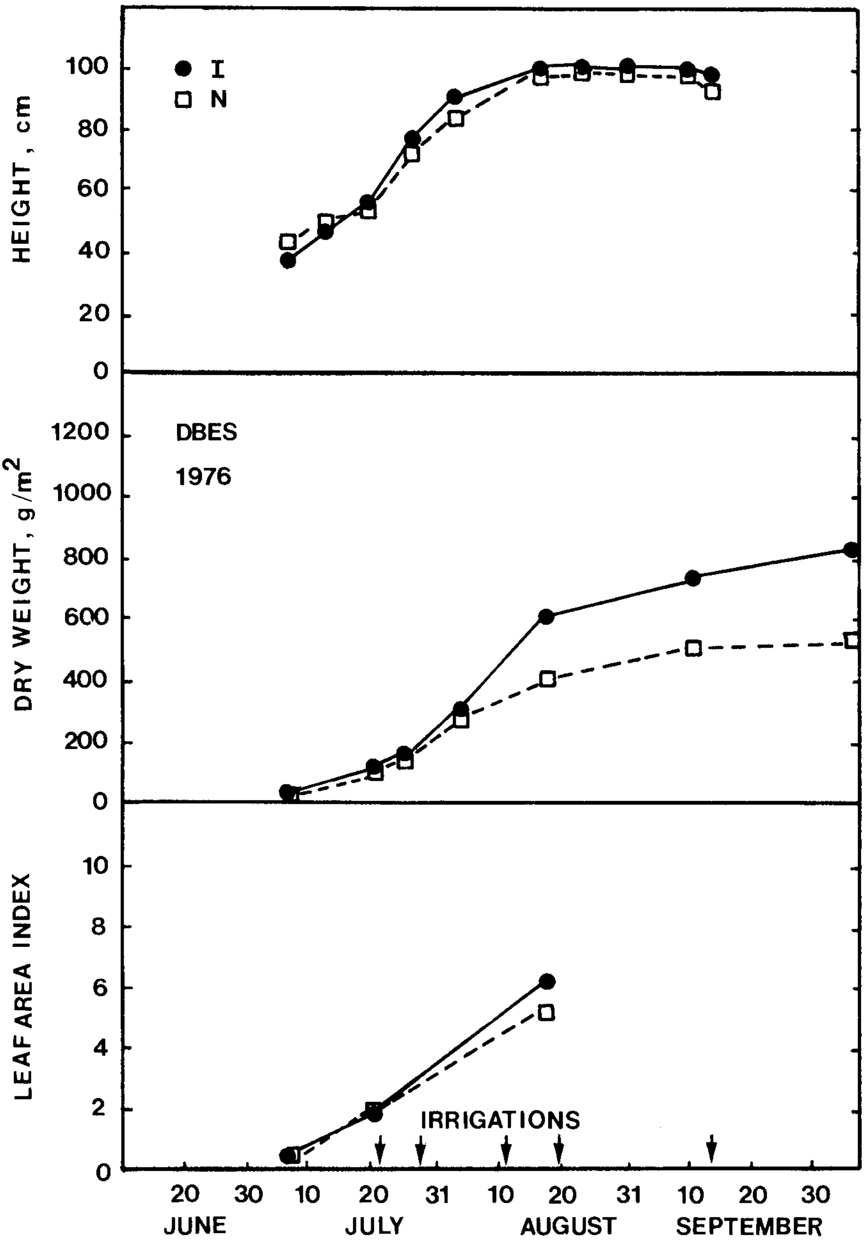

Figure 23. Height, dry weight, and leaf area index of the irrigated (I) and nonirrigated (N) soybean at DBES, 1976.

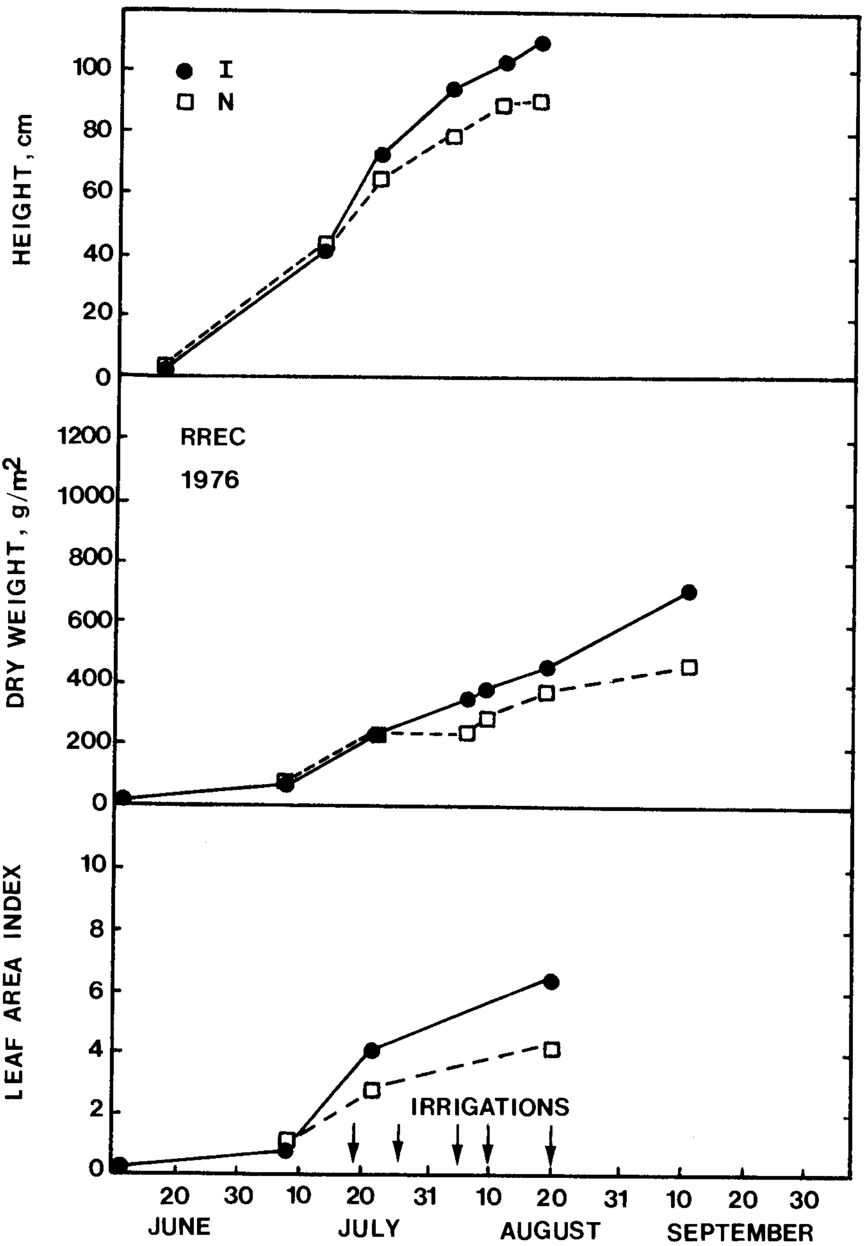

Figure 24. Height, dry weight, and leaf area index of the irrigated (I) and nonirrigated (N) soybean at RREC, 1976.

At RREC differential growth because of soil moisture treatment was initially found on 22 July (Fig. 24). By 20 August the soybean from the I plots were 20 cm taller, 80 g/m^2 heavier, and had 2.1 m^2/m^2 more leaf area than soybeans from the N plots. Although plant heights and leaf areas were not taken after 20 August, differences in dry weight suggest that differences in height and leaf area also persisted until maturity.

The seasonal soil water pressures at the 30- and 122-cm depths for the I and N plots are presented in Figures 25 and 26. At DBES on the Kobel soil the water pressures in the I plots varied from 0 to -520 cm of water at the 30-cm depth and from -30 to -165 cm of water at the 122-cm depth. In the N plots the soil water pressures at the 30-cm depth varied from -122 cm to a pressure beyond the tensiometer's working range of -850 cm of water. Because of the lack of rainfall during July and August most of the soil water pressure measurements were lower than -850 cm of water. At the 122-cm depth the range of soil water pressures in the N plots during the growing season was between -10 and -230 cm of water. As the growing

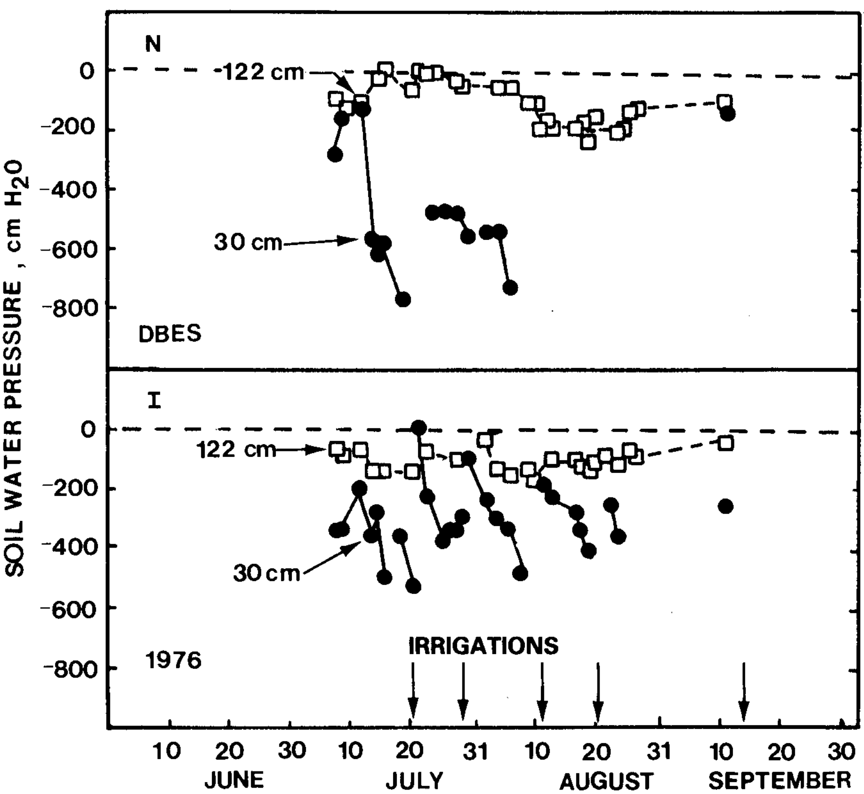

Figure 25. Seasonal soil water pressures at the 30- and 122-cm depths in the irrigated (I) and nonirrigated (N) plots on the Kobel soil during the 1976 growing season.

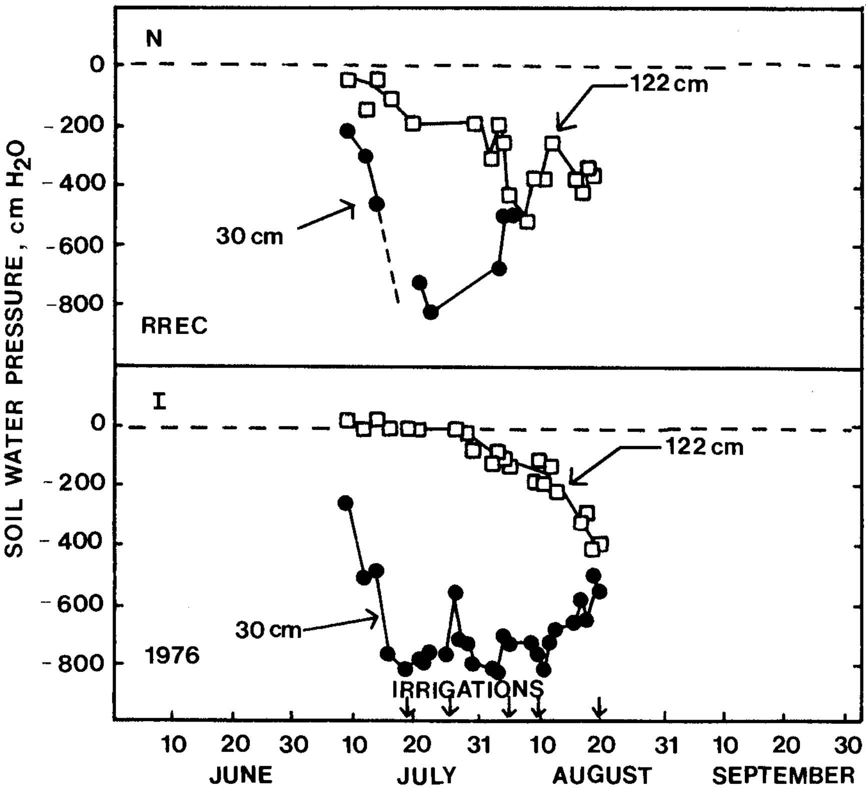

Figure 26. Seasonal soil water pressures at the 30- and 122-cm depths in the irrigated (I) and nonirrigated (N) plots on the Crowley soil during the 1976 growing season.

season progressed, the water pressures at the 122-cm depth decreased to a minimum of -230 cm by 19 August. The results indicate that in the Kobel soil, soybean roots extracted some water at the 122-cm depth even though the observed values of soil water pressures remained relatively high.

At RREC (Figure 26) a slightly different seasonal distribution of soil water pressures was found on the Crowley soil. In the I plots the soil water pressures at the 30-cm depth declined to -820 cm of water by 19 July but the pressures increased during August. The soil water pressures at the 30-cm depth did not reflect the irrigations of 19 and 26 July. This can be attributed to the slow redistribution rates of irrigation water throughout the soil profile. The most probable causes of the slow redistribution rates are the compaction of the Crowley soil near the soil surface and the presence of a plow pan between the 10- and 15-cm depths. Plow pans are known to restrict the internal transport of water in soil. At the 122-cm depth the soil water pressures generally decreased. By 20 August the average pressure was -410 cm of water. The positive pressure of 20 cm on 9 July indicates that a water table was present at the 122-cm depth early in the growing season. As the soybean roots explored a greater volume of soil, more water was extracted from the soil at the 122-cm depth. Similar results were found with the N plots. Because of the long interval between rainfall events, the tensiometers at the 30-cm depth were functioning only on eight observation days. This indicates that the stored water that the soybean roots extracted from the soil was not replenished by rainfall. At the 122-cm depth the soil water pressures decreased from approximately -40 cm of water on 9 July to -520 cm on 8 August. After the latter date the water pressures remained relatively constant at -380 cm of water.

Seed yields of the Lee 74 soybeans grown at the two locations in 1976 are presented in Table 5. At DBES yield increases above the nonirrigated soybean were 1210 and 329 kg/ha for soybeans in the I and B plots, respectively. This indicates that the one irrigation on 9 August increased seed yield by 329 kg/ha. This yield increase, however, was considerably lower than the increase that resulted from the five irrigations of the I plots. The average seed yield at DBES was 2092 kg/ha.

At RREC yield increases above those obtained with the N soybean were 1277 and 826 kg/ha for soybeans in the I and B plots, respectively. Thus, the three irrigations on 29 July and on 5 and 10 of August increased seed yields of soybeans in the B plots over those of the N plots, but the yield from soybeans in the B plots remained lower than the yield from the I plots. The average seed yield at RREC was 2365 kg/ha.

GENERAL SUMMARY

Lee 74 soybean was grown for three seasons on two soils and under three soil moisture treatments. The soybeans were irrigated whenever the soil water pressure was approximately -500 cm of water at the 30-cm depth. The response of the soybean to the moisture treatments was determined by frequent measurements of height, dry weight and leaf area during the growing season and by seed yields at harvest. The water status of the plant was also quantitatively determined by seasonal and diurnal measurements of U_l and U_o.

A comparison of the cumulative rainfall and pan evaporation is shown for RREC during the three growing seasons in Figure 27. The cumulative rainfall distributions during the three seasons were markedly different, yet the cumulative potential evaporation distributions were similar. Potential evaporation as estimated by pan evaporation far exceeded rainfall in two years out of three. Since little differences in potential evaporation would be expected between DBES and RREC, these data are representative of the climatic variability during the growing season in the mid-South. Even during a growing season with normal rainfall (34.3 cm at RREC), soil water deficits can occur from poor rainfall distributions and/or from runoff caused by rainfall rates exceeding infiltration rates of the soil. Our data indicate that under normal cropping conditions Lee 74 soybean requires between 50 and 60 cm of water during a growing season. Assuming that all rainfall is effective, between 15 and 25

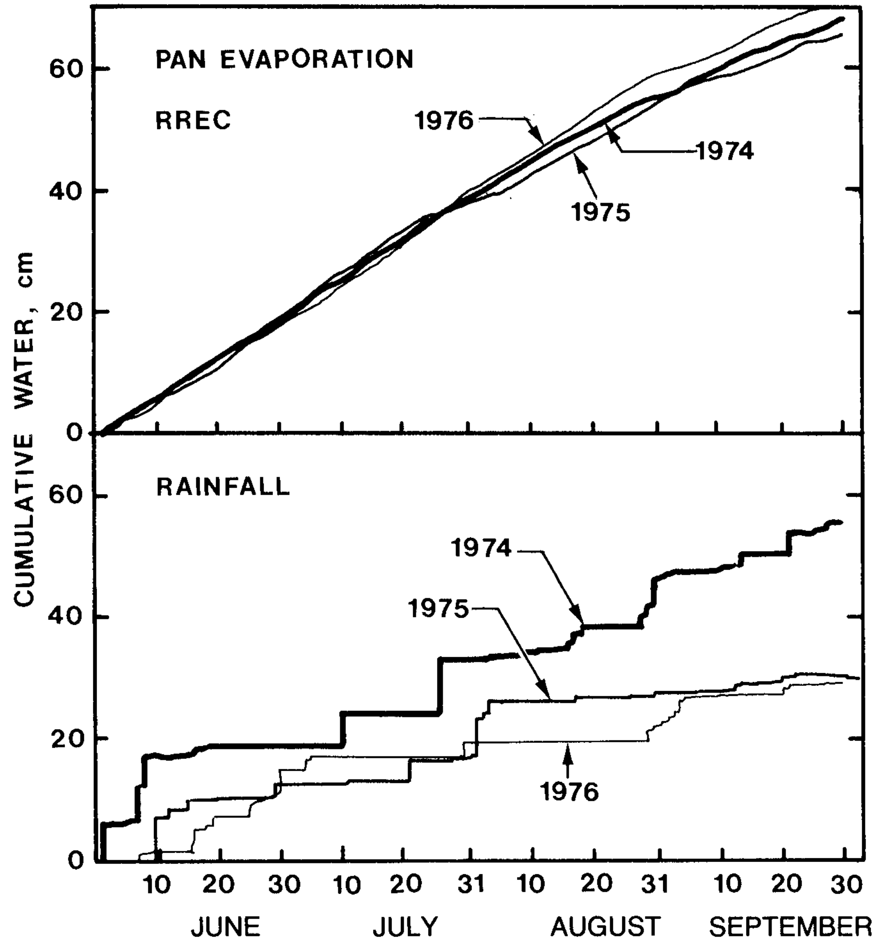

Figure 27. Cumulative water gained or lost as a function of time during the three growing seasons.

cm of water must be obtained from soil storage and irrigation. Neither the Crowley nor the Kobel soil contain more than 18 cm of extractable water in the profile for soybean. Thus, severe soil water deficits will occur in most years resulting in plant water deficits and reduced yields. One must conclude, therefore, that for maximum yield of soybean on the Crowley and Kobel soils, timely irrigation will be required in most years.

Water was extracted from a depth of at least 122 cm in both soils by August even though the root density was low in the lower portion of the soil profile. Usually the nonirrigated soybean began to extract water at the 122-cm depth one to three weeks earlier than soybean from the I plots. This delay in the I plots can be attributed to extraction of the irrigation water near the soil surface. Soybean roots have been shown to exert a significant resistance to the flow of water in the plant (15). This resistance contributes to the plant's preference for using water near the soil surface.

The effects of drought on the seed yields of Lee 74 and the response to timely irrigations for the three growing seasons are summarized in Table 5. Maximum yields were obtained with the I treatment and averaged 2439 kg/ha at DBES and 2890 kg/ha at RREC. With one exception these yields were relatively stable over the three-year study. It is our conclusion that the yields at DBES in 1974 were much lower than normal because of the late harvest, and therefore, the average maximum yield at this location is conservative.

Yields of the B soybean were between the N and I treatment yields, indicating that significant benefit can still be obtained by waiting until the soybeans enter the reproductive growth stages before applying supplemental water. It should be emphasized, however, that the average yields from soybean in the B plots were 522 and 473 kg/ha lower than those from the I plots at DBES and RREC, respectively. Thus, loss of maximum yield had occurred as a result of the delay in irrigation.

Over the three-year period the nonirrigated soybean averaged 1633 kg/ha at DBES and 2068 kg/ha at RREC. Differences in average yield between the I and N plots were 806 kg/ha at DBES and 822 kg/ha at RREC. These values are similar and indicate that the response of the Lee 74 soybeans to irrigation on the two soils was similar.

On a percentage basis, full-season irrigation increased yields by 49.4 percent at DBES and 39.7 percent at RREC. Waiting until reproductive growth to apply the irrigation water increased yields by 17.4 percent at DBES and 16.9 percent at RREC. When only the two relatively dry years (1975 and 1976) are considered, the beneficial effects of irrigation of Lee 74 soybean increase substantially.

Average yield increases over the nonirrigated soybean due to irrigation in the dry years were 1257 kg/ha at DBES and 1223 kg/ha at RREC. This represents a two-year average percentage increase of 79.1 percent at DBES and 70.1 percent at RREC. Waiting until reproductive stage to initiate the irrigations increased yields in the dry years by 453 kg/ha at DBES and 447 kg/ha at RREC. The percentage increases with the B treatment were 28.5 percent at DBES and 25.6 percent at RREC. The percentage increases are similar to those found by Spooner (14) and Thompson and Brown (16) on the same soil.

CONCLUSIONS

Results of this three-year study lead to the following conclusions:

1. Soybean yields can be increased and sustained at high levels by irrigation scheduling that uses quantitative techniques with instruments such as tensiometers to determine when to irrigate. The dependability of this instrument to schedule irrigation was demonstrated during both wet and dry years.

2. In the mid-South variability of rainfall within a growing season is high compared

to that of potential evaporation. Since the evaporative demand and crop water requirements are considerably greater than the sum of the long-term mean rainfall and of water storage in the soil profile, additional water will be needed in most growing seasons if maximum yields are to be achieved.

3. Soils such as Crowley that have horizons or zones that restrict water movement near the soil surface will reduce the rate at which water effectively enters the profile and will necessitate earlier irrigation and more frequent irrigation during the growing season.

4. When rainfall during July was below normal, differences in plant growth were initially found during late July when the Lee 74 soybean were in late vegetative growth stages. The effects of drought on plant water status were more evident during late reproductive growth than during vegetative growth. Critical parameters were the rate of decline of the xylem water pressure potential after sunrise, duration of depressed xylem pressure potentials during the day, and rate of recovery to unstressed xylem pressure potentials during late afternoon and night. These led to lower values of dry matter accumulation, height, and leaf area index for the nonirrigated soybean.

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APPENDIX

Table A. Morphological profile description of the Crowley soils at the study site.

Soil	Horizon	Depth	Description
Crowley	Ap1	0–10cm	Brown to dark brown (10YR 4/3) silt loam; massive to weak fine granular structure; very friable; many very fine roots and very fine pores; few fine Fe-Mn concretions; abrupt smooth boundary.
	Ap2	10–18cm	Grayish brown (10YR 5/2) silt loam; common fine brown to dark brown (7.5YR 4/4) and strong brown (7.5YR 5/6) mottles; massive with areas of weak very thick platy structure, very firm to extremely firm; very fine roots; few very fine pores; abrupt smooth boundary.
	Eg	18–37cm	Light gray (10YR 7/2) silt loam; many medium yellowish brown (10YR 5/6) and few fine red (2.5YR 4/6) mottles; weak coarse subangular blocky structure; friable; common very fine roots and fine vertical root channels; few fine Fe-Mn concretions; clear wavy boundary.
	Btgl	37–75cm	Mottled red (2.5YR 4/6) and Light brownish gray (10YR 4/2) clay; weak medium prismatic to moderate medium angular blocky structure; friable; few very fine roots and very fine vertical root channels; common very fine pores; gradual smooth boundary.
	Btl	75–98cm	Red (2.5YR 4/6) silty clay; many medium light brownish gray (10YR 6/2) mottles; weak medium prismatic to moderate medium angular blocky structure; firm; medium continuous clay films; few very fine roots and very fine vertical root channels; common very fine pores; gradual smooth boundary.
	Bt2	98–125cm	Yellowish brown (10YR 5/4) silty clay; common fine light brownish gray (10YR 6/2) and few fine red (2.5YR 4/6) mottles; weak to moderate coarse angular and subanglar blocky structure; very firm; few very fine roots and vertical root channels; common very fine pores; gradual smooth boundary.

Table B. Morphological profile description of the Kobel soils at the study site.

Soil	Horizon	Depth	Description
Kobel	Ap1	0–10cm	Dark grayish brown (10YR 4/2) light silty clay; massive; firm; few very fine pores and fine roots; abrupt smooth boundary.
	Ap2	10–21cm	Dark grayish brown (10YR 4/2) light silty clay; common fine yellowish brown (10YR 5/6) mottles; weak coarse angular blocky structure; firm, few very fine pores and fine roots; clear smooth boundary.
	Bg1	21–64cm	Dark gray (10YR 4/1) light silty clay; common fine yellowish brown (10YR 5/6) and brown to dark brown (7.5YR 4/4) mottles; weak to moderate medium angular blocky structure; very firm; few to common fine pores and very fine roots; gradual smooth boundary.
	Bg2	64–108cm	Dark grayish brown (10YR 4/2) light silty clay; common fine yellowish brown (10YR 5/6) and brown to dark brown (7.5YR 4/4) mottles; moderate medium angular blocky structure; very firm; few to common fine pores and very fine roots; gradual smooth boundary.
	Bg3	108–197cm	Dark gray (10YR 4/1) light silty clay; few fine brown to dark brown (.7.5YR 4/) mottles; weak prismatic to moderate medium angular blocky structure; very firm; few fine pores and very fine roots; clear wavy boundary.

Table C. Summary of the growth stage evaluations of the Lee 74 soybean grown at the two locations.

Growth	1974		1975		1976	
Stage	DBES	RREC	DBES	RREC	DBES	RREC
V1					6–9	
V2						6–11
V3		7–15				
V4						
V5						
V6						
V7					7–7	
V8		8–30		7–3		7–8
V9		8–2	7–9	7–8		7–8
V10						
V11					7–21	7–23
V12		8–9	7–22	7–23		
R1				8–4		7–28
R2	8–6	8–13			8–4	8–5
R3				8–23	8–13	
R4	8–21	8–28	8–22			8–20
R5	8–27	9–5				
R6	9–19			9–26	9–11	9–11
R7	10–8	10–9		10–7		

Table D. Monthly summaries of the average air temperature, rainfall and pan evaporation at the two study locations during the three growing seasons.

Location	Year	Month	Average Temp.	Total Rainfall	Evaporation[1]
			C	cm	cm
DBES	1974	June	23.1	32.4	
		July	27.8	10.0	
		August	25.2	19.8	
		September	19.4	7.4	
	1975	June	25.4	4.8	
		July	26.9	2.9	
		August	26.9	2.8	
		September	20.7	9.5	
	1976	June	24.1	13.4	
		July	27.0	12.2	
		August	25.4	0	
		September	22.1	3.9	
RREC	1974	June	23.2	19.2	19.5
		July	27.8	14.5	21.3
		August	25.6	13.2	17.4
		September	19.4	9.9	9.9
	1975	June	25.4	12.8	18.8
		July	27.0	4.2	19.6
		August	26.3	10.0	16.4
		September	21.2	2.8	12.7
	1976	June	23.8	15.2	18.5
		July	26.9	4.2	22.2
		August	25.8	3.0	20.0
		September	21.8	6.8	11.3

[1]No pan evaporation data were recorded at DBES.